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Guide to Optimal Groundwater Monitoring

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LIST OF ACRONYMS

AFCEE	Air Force Center for Environmental Excellence
AMC	Air Mobility Command
ANOVA	analysis of variance
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CNO	Chief of Naval Operations
COC	contaminant of concern
COM	center of mass
CSM	conceptual site model
DEM	Digital Elevation Map
DENIX	Defense Environmental Network and Information Exchange
DI	deionized
DoD	Department of Defense
DON	Department of the Navy
DQOs	Data Quality Objectives
EFA	Engineering Field Activity
EFAWEST	Engineering Field Activity West
EFD	Engineering Field Division
EFD/As	Engineering Field Divisions/Activities
EPA	Environmental Protection Agency
EVS	Environmental Visualization System
GIS	geographic information system
GMP	Groundwater Monitoring Plan
GMR	Groundwater Monitoring Report
GPS	Global Positioning System
IDW	Investigation-Derived Waste
IR CDQM	Navy Installation Restoration Chemical Data Quality Manual
IRP	Installation Restoration Program
ITRC	Interstate Technology and Regulatory Cooperation
LDPE	low-density polyethylene
LSD	least significant difference
MCB	Marine Corps Base
MCL	Maximum Contaminant Level

MDL	method detection limit
MNA	monitored natural attenuation
NAS	Naval Air Station
NAVFAC	Naval Facilities Engineering Command
ND	non-detect
NFESC	Naval Facilities Engineering Service Center
NRC	Nuclear Regulatory Commission
NWIRP	Naval Weapons Industrial Reserve Plant
OU	Operable Unit
PARCC	precision, accuracy, representativeness, completeness, and comparability
PA/SI	Preliminary Assessment/Site Investigation
PCB	polychlorinated biphenyl
POC	point of compliance
PRG	Preliminary Remediation Goal
QA/QC	quality assurance/quality control
RC	Response Complete
RI/FS	Remedial Investigation/Feasibility Study
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
RPM	Remedial Project Manager
SDT	significant difference test
SOW	statement of work
SQL	sample-specific quantitation limit
SVOCs	semivolatile organic compounds
SWDIV	Engineering Field Division Southwest
TAL	Total Analyte List
TCE	trichloroethene
TCL	Total Compound List
TNRCC	Texas Natural Resources Conservation Commission
USAF	United States Air Force
USGS	United States Geological Survey
UST	underground storage tank
UTL	upper tolerance limit
VOCs	volatile organic compounds
WWW	World Wide Web

1.0 Introduction

The Department of the Navy (DON) recently formed a Working Group to provide guidance to the DON activities for optimizing groundwater monitoring programs at Navy installations. This Working Group, which is led by the Naval Facilities Engineering Service Center (NFESC), is made up of engineers and scientists from NFESC, Naval Facilities Engineering Command (NAVFAC), Engineering Field Divisions/Activities (EFD/As), and Chief of Naval Operations (CNO).

1.1 Purpose

One purpose of the Working Group is to create this *Guide to Optimal Groundwater Monitoring*, which can be used by Navy Remedial Project Managers (RPMs) to ensure that their monitoring programs are designed and periodically optimized to cost-effectively support their monitoring goals. The objective of this guidance document is to provide information that Navy RPMs and their contractors can readily implement to:

- Design new monitoring programs that will achieve monitoring objectives cost effectively; and
- Optimize existing monitoring programs to reduce monitoring costs while maintaining program effectiveness.

This document is intended to be general enough to apply to a variety of site conditions, but at the same time provide specific guidance for monitoring program optimization. It is not intended to make monitoring experts of RPMs, but to provide them with the information they need to understand main points of monitoring program design and optimization.

1.2 Key Points of This Guide

The *Guide to Optimal Groundwater Monitoring* focuses on the most significant ways to design and optimize groundwater monitoring programs in order to maximize cost-effectiveness without compromising program and data quality. The five general strategies that ensure a cost effective monitoring program include:

- Reducing the number of monitoring points;
- Reducing monitoring duration and/or frequency;
- Simplifying analytical protocols;
- Ensuring efficient field procedures; and
- Streamlining data management and reporting.

Ideally, these principles are applied when designing a program and are continually revisited as the monitoring program progresses.

Another key point emphasized within this document is the importance of having a Groundwater Monitoring Plan (GMP). A GMP is an important tool in conducting an efficient monitoring program, as it contains the decision criteria for decreasing and eventually ceasing monitoring at your sites. The optimum approach is to have a regulator-approved GMP in place before starting a monitoring program.

1.3 Key Resources

In part, “lessons learned” from monitoring optimization case studies performed at several Navy installations were used to write the *Guide to Optimal Groundwater Monitoring*. These case studies covered a wide range of remediation sites with differing monitoring requirements. Examples from these case studies are provided throughout this document to highlight technical points and concepts. Summaries of the case study reports for three installations are provided in Appendix A of this document. Internal

Navy case studies, where EFD/As undertook actions to optimize their own groundwater monitoring programs, are provided in Appendix B.

Other Department of Defense (DoD) documents were referred to for additional ideas on optimizing monitoring programs at military installations. Specifically, the Air Force Center for Environmental Excellence (AFCEE) Long-Term Monitoring Optimization Guide (AFCEE, October 1997) was used as a model for this document. Section 10 lists other monitoring optimization resources.

1.4 Organization of This Document

This document is organized as follows:

Section 2, What is the Goal of the Monitoring Program?—Prior to any design or optimization activities, you must define your monitoring goals. This section introduces several tools and considerations to help you formulate your program goals.

Section 3, Where Should I Monitor? How Many Monitoring Points Do I Need?—The first step to designing or optimizing a groundwater monitoring program is to identify monitoring points that provide the right amount of coverage in the right locations. Section 3 explains the basics of monitoring network design.

Section 4, How Often Should I Monitor? For How Long?—This section identifies tools for determining appropriate monitoring frequency and duration, including decision criteria and groundwater modeling.

Section 5, What Contaminants Do I Need to Monitor?—Tailoring the data collection and quality assurance practices to the goals of the monitoring program will ensure that you are not managing and reporting excessive amounts of data. Section 5 stresses the importance of collecting the right types of data and defining appropriate quality assurance requirements.

Section 6, How Should I Collect the Samples?—There is more to collecting a sample than just "filling a bottle." This is one of the most important steps of the monitoring process. This section will introduce ways to improve your sample quality and representativeness, while decreasing sampling costs.

Section 7, How Do I Evaluate and Present My Data So It's Easy to Understand?—Your periodic monitoring reports shouldn't be a "data dump." Make them clear, concise, and easy to understand. From evaluating your data to reporting and presenting your data, Section 7 provides ideas to save you time and money while improving your understanding of the site.

Section 8, How Can I Ensure Regulatory Acceptance?—Effective communication is the cornerstone of any relationship. This is especially true of the relationship between you and your regulator. This section provides strategies for making your regulator part of the monitoring team.

Section 9, What Tools Can I Use to Facilitate Optimization of My Monitoring Program?—This section provides additional tools that can be applied to facilitate monitoring optimization from start to finish.

Section 10, Where Else Can I Go for Help?—There are many resources for designing and optimizing a monitoring program. Section 10 provides a partial list of readily available optimization resources. This list includes Environmental Protection Agency (EPA) publications, technical papers, and useful web sites.

Section 11, References—This section provides a list of the documents cited in this guide.

2.0 What is the Goal of the Monitoring Program?

Content: *This section introduces the concept of monitoring optimization and presents tools you can use to define the objectives of your monitoring program. These tools include:*

- *Conceptual site models (CSMs);*
- *Data quality objectives;*
- *Regulatory framework;*
- *Groundwater Monitoring Plans (GMPs); and*
- *Annual and 5-year program review.*

2.1 What is Monitoring Optimization?

As the Installation Restoration Program (IRP) at DON installations matures, more money is spent on monitoring. As monitoring program costs become a significant portion of the IRP budget, it becomes increasingly important to evaluate these programs in terms of cost effectiveness.

The primary objective of optimizing monitoring programs is to reduce monitoring costs without compromising program quality or effectiveness. To this end, the optimization process focuses on collecting relevant data of the appropriate quality to achieve program goals. This can be done by evaluating the following aspects of your monitoring program in light of the overall program goals:

- The number of monitoring points;
- The frequency and duration of monitoring;
- The analyte list and quality assurance/quality control (QA/QC) samples;
- The sampling procedures; and
- The data evaluation, management, and reporting procedures.

The remainder of this section is aimed at helping you define your monitoring goals so that you can effectively evaluate the above points.

2.2 Defining and Documenting the Goals of Your Monitoring Program

Before designing an effective monitoring program, you must ask yourself "What is the goal of monitoring at this site?" Typically, monitoring objectives fall into one or more of the following categories:

- Validate the conclusions of a remedial investigation/feasibility study (RI/FS);
- Determine if contamination is migrating off site or off base;
- Determine if contamination will reach a receptor (such as a drinking water supply well);
- Track contaminants exceeding some standard;
- Track the changes in shape, size, or position of a contaminant plume;
- Assess the performance of a remedial system (including monitored natural attenuation [MNA]);
- Assess the practicability of achieving complete remediation; or
- Satisfy regulatory requirements (such as those for landfill closure).

Following formal definition, the goals of your monitoring program are described and documented in the GMP. The GMP will become the definitive document for operational guidance on your specific monitoring program. In addition to GMPs, this section focuses on some common tools available to help guide RPMs in defining and documenting their monitoring program goals, including the following:

- The conceptual site model (CSM);
- The regulatory framework;

- Data quality objectives (DQOs); and,
- Performance monitoring.

2.2.1 Conceptual Site Model

The first step in identifying goals of a monitoring program is to understand what problems exist at the site. A CSM is useful in the initial and on-going description of all parameters relevant to contamination at a site. Figure 2-1 shows one example of a CSM. In essence, the CSM provides a picture—both historical and current—of the problem that must be addressed. A good CSM addresses the following elements:

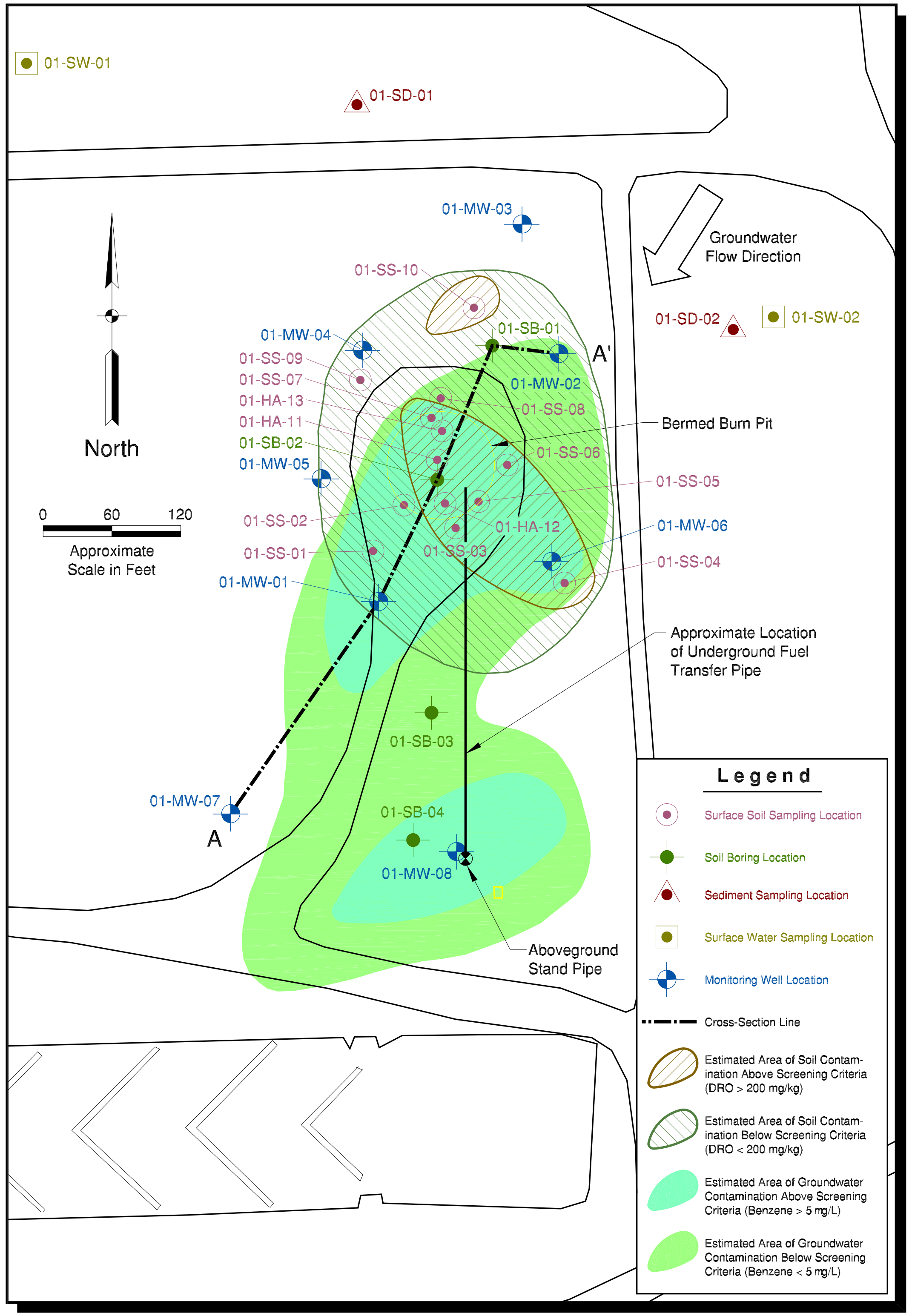
- Nature and extent of contamination;
- Geology;
- Hydrogeology;
- Biological and geochemical conditions;
- Transport pathways of contamination;
- Monitoring points;
- Receptors and potential receptors;
- Historical uses; and
- Other factors relevant to the understanding of contamination at the site.

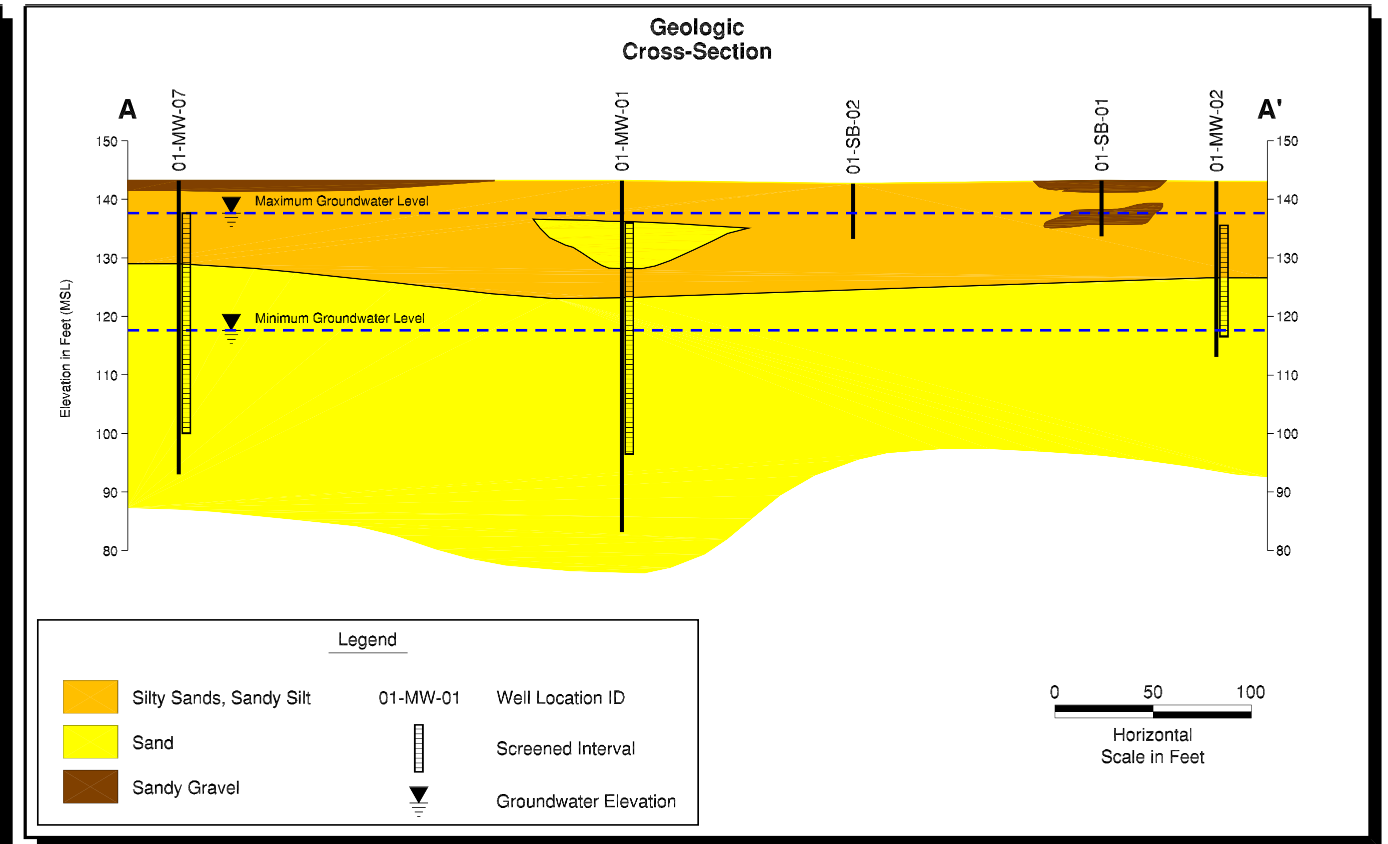
The CSM represents your understanding of the site. As such, the CSM will be used to convey the entire understanding of the site to the appropriate regulators. Specific monitoring program goals will be defined based upon the regulatory requirements for the site in question.

The CSM can also be used to expose data gaps and aid in design of the monitoring network. As a modeling tool, the CSM can be updated periodically with performance monitoring data to show progress towards goals, and reevaluate corrective measures, monitoring strategies, and possibly, the goals of the program. A detailed description of CSMs can be found in the American Society for Testing and Materials (ASTM) *Standard Guide for Developing Conceptual Site Models for Contaminated Sites* (ASTM, 1995).

2.2.2 Regulatory Framework

Whether already imposed or otherwise anticipated, it is the underlying host of Federal, State, and local regulations that effectively drive all remedial measures, protective monitoring, and compliance monitoring at contaminated sites. These regulations all have the common theme of providing protection to human health and the environment. Nevertheless, distinctions in which regulatory program, or framework, that a site falls under will help in determining the overall goal of the monitoring program. For instance, regulatory requirements for groundwater monitoring design at a site may vary based on whether it is regulated under the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or a state underground storage tank (UST) program. Accordingly, the regulatory end points for specific contaminant concentrations required for achieving closure requirements may also differ based on the regulatory framework.





Compounds Exceeding Screening Criteria

Analyte	Soil Screening Criteria (mg/kg)	Soil Range of Detections (mg/kg)	Groundwater Screening Criteria (mg/L)	Groundwater Range of Detections (mg/L)
Benzene	500 S	3,000 - 120,000	5 M	22 - 420
Benzo(a)pyrene	780 RC	2.7 - 1,500		
Ethylbenzene	15,000 S	2,300 - 200,000		
Toluene	15,000 S	1.4×10^4 - 1.1×10^6		
Xylenes	15,000 S	1.2×10^4 - 1.2×10^6		
DRO	200,000 S	27,000 - 7.2×10^7		
GRO	100,000 S	130,000 - 2.4×10^7		

Key:
S - State Cleanup Standard
RC - EPA Region III Risk-Based Concentration, Carcinogenic
M - Maximum Contaminant Level

Site History

Fire training activities have been conducted at this site since the late 1950's. Drums of flammable materials have been stored around the burn pit. An underground pipeline, located to the south of the burn pit, was used to deliver flammable liquids to the pit during training exercises. Approximately 300 to 500 gallons of fuel, primarily clean and contaminated JP-4, were used per fire. The site has been closed since 1991.

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Figure 2-1. Example Conceptual Site Model

A standardized list of regulatory requirements is not available because they depend entirely, or in part, on site-specific conditions. The definition of the regulatory end point, or preliminary remediation goals (PRGs), may be based on localized background concentrations of a given contaminant, or may be contingent upon findings of a baseline risk assessment for that site. Virtually all states have an Internet site that, at the very least, provides contact information for key personnel at the state environmental agency. Many states post their regulations in a searchable format. Section 10 provides World Wide Web (WWW) addresses for the environmental agencies of all 50 states. If you can't find regulations that specifically address monitoring programs for your state, you will have to negotiate with your regulator to establish a set of goals that satisfy all requirements of the relevant regulatory framework. Strive to get agreement on monitoring goals from all stakeholders as soon as possible. Section 8 discusses regulator relationships in more detail.

2.2.3 Data Quality Objectives (DQOs)

The EPA DQO process is discussed in *Guidance for the Data Quality Objective Process* (EPA QA/G-4, September 1994). The purpose of the DQO process is to define the types and quality of data necessary to support the decisions you will make during site monitoring. In other words, the DQOs must support the overall objective of your monitoring program. Table 2-1 outlines the seven steps in the DQO process and gives examples of each that apply to monitoring programs.

Table 2-1. Data Quality Objective Process and Examples

DQO Process Step	Example
State the problem.	Trichloroethene (TCE) in groundwater upgradient of a supply well exceeds the Maximum Contaminant Level (MCL).
Identify the decision.	Determine when treatment and monitoring can be stopped without compromising human health.
Identify the inputs to the decision.	Monitoring data for TCE, system performance results.
Define the study boundaries.	Radius of influence of the treatment system and the extent of the monitoring system.
Develop a decision rule.	Treatment may be stopped with continued monitoring once TCE concentrations remain below the MCL for eight quarterly sampling rounds and system performance has leveled off.
Specify tolerable limits on decision errors.	Decision errors resulting in excess monitoring and treatment are acceptable. Decision errors negatively affecting human health are not acceptable (i.e., a very high confidence that the treatment has brought site concentrations below the MCL is necessary before stopping treatment and monitoring at the site).
Optimize the design.	Perform highest level of quality assurance/quality control (QA/QC) and data validation procedures on monitoring data. Conduct geostatistical analysis of site data to confirm with a high degree of confidence that groundwater at the site is consistently and reliably below the MCL.

2.2.4 Performance Monitoring

The primary purpose of performance monitoring is to provide the quantity and quality of data necessary to make informed decisions regarding remedial system operation, and to verify progress toward your overall monitoring program goals. A properly designed performance monitoring system will provide you with feedback on the effectiveness of the site remedy and supply the data necessary to assess progress toward program goals. An effective performance monitoring network should allow you to (AFCEE, July 1999):

- Track the horizontal and vertical extent of contamination;
- Measure the change in contaminant concentration resulting from treatment (including MNA) and estimate the mass of contaminant reduction;
- Compare data to all decision criteria and exit points;
- Measure the rate and direction of any contaminant migration to confirm containment or noncontainment; and
- Determine the effects of contaminant source areas on remedy effectiveness.

Performance monitoring results should be incorporated into a CSM as the monitoring program progresses. In this manner, the CSM will provide a current picture of conditions at the site. Because conditions change over time, especially where active treatment is taking place, it is necessary for an ongoing process of examining sample locations, frequencies, and analytical methods to ensure that the right amount and type of data are being collected. Rationale for including monitoring wells and determining sampling frequency is provided in Sections 3 and 4 of this report.

2.2.5 Groundwater Monitoring Plans (GMPs)

Once you have defined the goals of your monitoring program, it is essential to document them. The Groundwater Monitoring Plan (GMP) is the ideal format for this. The primary purpose of the GMP is to specify how the monitoring program will be conducted in order to meet the site-specific objectives. It allows for consistent data collection and comparability and documents the monitoring approach in the event of installation, contractor, or regulatory personnel turnover. The following components should be included in your GMP:

- Statement of program goals;
- Current monitoring network;
- Frequency and anticipated duration of monitoring;
- Specific field procedures (e.g., purging, sampling, decontamination, record keeping, etc.);
- Analytical methods, sample handling requirements (e.g., containers, preservation), and quality assurance/quality control (QA/QC) sample collection rates;
- Data handling and reporting procedures; and
- Decision criteria (including exit strategies) and review process to periodically optimize all of the above.

Section 2.3 provides additional information on using a regular review process to optimize the monitoring program and modify the GMP. Section 8 discusses obtaining regulator buy-in via the GMP.

2.3 Reevaluating the Goals of Your Monitoring Program

It is important to reevaluate the goals of your monitoring program on a regular basis. Annual and 5-year reviews are an opportunity to make changes to your monitoring program and the GMP, if necessary. Although 5-year reviews are required by CERCLA and many RCRA permits, an annual review process is strongly recommended for maintaining an optimal monitoring program.

2.3.1 Annual Reviews

Annual reviews should be conducted to determine if the monitoring goals have been achieved at any of your sites, or if the past year of site data result in any changes to the program goals. It may be helpful to conduct annual reviews well in advance of budgeting for the next fiscal year. This way, if any changes in funding needs are identified during the annual review, they can be incorporated into the budget requests in a timely manner.

Following are some of the steps you may need to take during the annual review of your monitoring program:

1. Review all analytical data generated during the last year. Does the new information validate the historical data? Or are there significant changes to contaminant concentrations or plume size and shape (nature and extent)?
2. If applicable, review any available MNA data, such as dissolved oxygen, total organic carbon, etc., to confirm that conditions are still suitable for this process to occur.
3. Review any hydrogeologic data collected during the last year. Are groundwater levels relatively constant? Or are there marked seasonal fluctuations? Are groundwater flow directions and flow rates consistent with the original hydrogeologic model formulated for the site?
4. If there is a remedial action being performed at the site (including MNA), is adequate progress being made toward the cleanup goals? On the basis of all data available, does it look like the cleanup goals will be achieved in a reasonable time frame? Does the remedial action still appear to be a protective option? Or are there new or different technologies that may be more efficient?
5. If a risk assessment was conducted for the site, verify that the assumptions used are still valid. Have any new pathways and/or receptors been introduced at the site?
6. Have any new regulatory standards or requirements been introduced? If so, how do site data compare to the new standards?

If any of the original assumptions that went into formulating the CSM or the DQOs have changed, the program goals may need to be modified. An updated CSM should be produced to reflect the new site understanding.

Example: *Marine Corps Base (MCB) Camp Lejeune regularly analyzes groundwater monitoring data, performs trend analysis, and contours the data to make recommendations for program improvements and to ensure that monitoring objectives are being met. The monitoring team (Base personnel, regulators, and contractor personnel) meets every two months to update current understanding of site conditions and make consensus recommendations for changes and improvements.*

2.3.2 Five-Year Reviews

Specifying a 5-year review period in a decision document, such as a record of decision (ROD), allows an opportunity to make formal changes to a monitoring program. The 5-year review may be used to help make decisions regarding the effectiveness of the remedy, including whether the system should be shut down and replaced with an alternative technology, or whether the site should be closed out based on the most recent five years of monitoring data. The 5-year review should be conducted with the involvement of all stakeholders, including installation personnel, contractors, regulators, and community members.

Preparation for 5-year reviews can be simplified by planning for them during all five of the preceding years. Groundwater Monitoring Reports (GMRs) should track recommendations, whether the recommendations were implemented, status of decision criteria, changes to monitoring goals, and changes to site conditions (via the CSM). In addition, proper data evaluation and visualization techniques, as discussed in Sections 7 and 9, can simplify preparation for 5-year reviews.

Example: *The monitoring contractors at MCB Camp Lejeune are tasked with making recommendations to streamline the monitoring program in each GMR. Subsequent GMRs outline which recommendations have been implemented and which are still pending, as well as specifying new recommendations based on* *the most current round of monitoring data. The GMRs also present the latest groundwater contaminant contour maps so that plume shape and size are constantly tracked.*

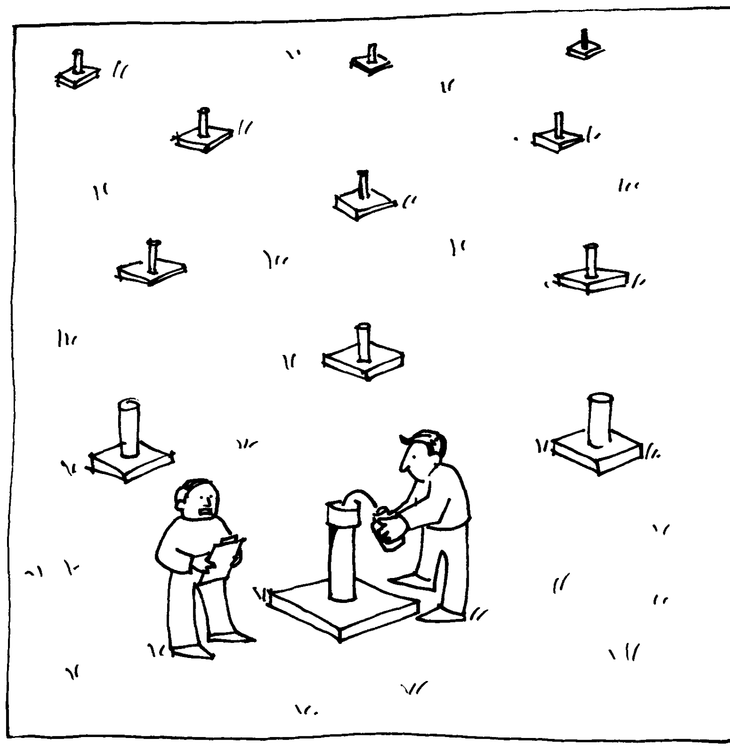
3.0 Where Should I Monitor? How Many Monitoring Points Do I Need?

Content: *This section discusses the basic considerations for designing a monitoring network that effectively addresses the goals of your program without being excessive. If you did not design the monitoring network up front, this section also covers optimizing the existing network. Tools for choosing monitoring points discussed in this section include:*

- *Groundwater flow calculations (see also Section 9.2);*
- *Decision criteria and diagrams; and*
- *Statistical tools (see also Section 9.1 and Appendix C).*

3.1 Designing a Monitoring Network

The number and placement of wells needed to ensure adequate monitoring of groundwater contamination will be a function of many site-specific characteristics. In addition, there are many things unrelated to site characteristics that may affect the design of your monitoring program. These include regulatory and community relations considerations.



Hurry up... it's almost time to start the next sampling round!

As a first step, a comprehensive review of applicable regulatory requirements should be conducted (see also Sections 8 and 10). In many cases, state regulatory agencies will have mandatory guidelines for the types and placement of compliance monitoring wells. Figure 3-1 provides an idealized illustration of the types of wells that may be required for monitoring at a given site; Table 3-1 describes these types of wells in more detail. Inclusion of additional sampling points at property boundaries or near politically sensitive areas may be warranted for community relations purposes.

Example: *The regulatory framework and monitoring objectives were considered when recommending which wells to include in the groundwater monitoring program at Naval Weapons Industrial Reserve Plant (NWIRP) Dallas. The Texas Natural Resources Conservation Commission (TNRCC) provided minimum requirements for the use of background wells, point-of-compliance (POC) wells, corrective action observation wells, and optional supplemental wells. The concerns of the surrounding community were also addressed by continued sampling of off-base wells. By interpreting the regulatory framework in light of the geohydrological model for the site, 56 wells were chosen from an existing groundwater monitoring network of nearly 300 wells.*

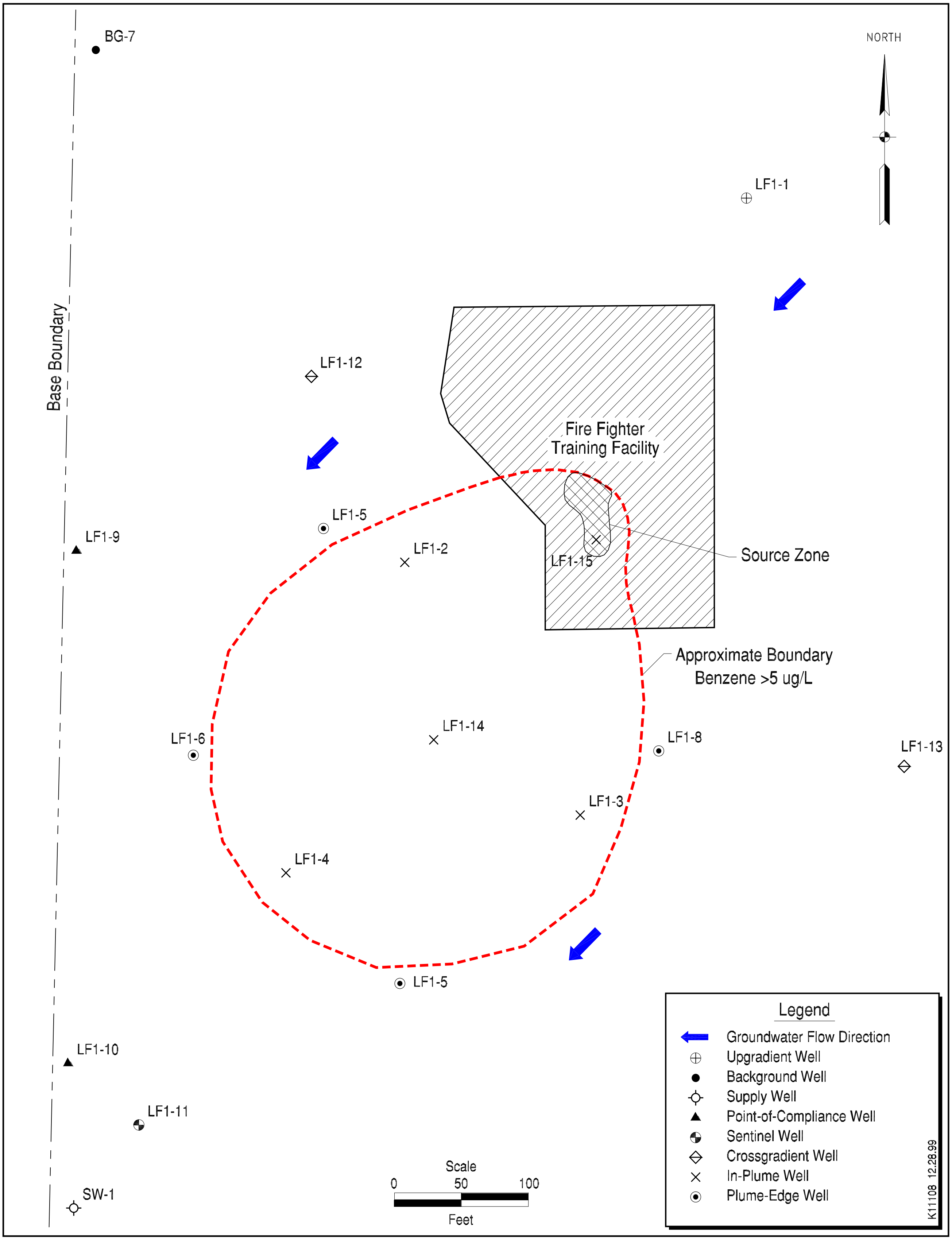


Figure 3-1. Idealized Monitoring Well Network

Table 3-1. Types of Monitoring Wells

Well Type	Location Relative to Source	Description
Upgradient	Upgradient	Upgradient wells are located away from the source of contamination in the direction from which groundwater flows. Concentrations in these wells represent contaminants flowing onto the site, if any. An uncontaminated upgradient well may be used as a background well.
Background	Upgradient or Crossgradient	Background wells are located where they cannot be affected by contamination. They are used to determine background concentrations of contaminants, usually metals or other naturally occurring compounds. An upgradient well may serve as a background well.
Crossgradient	Crossgradient	Crossgradient wells are located adjacent to the source of contamination in a direction perpendicular to the direction of groundwater flow. These wells may be used to ensure that diffusion, dispersion, or seasonal variations in flow direction do not result in the additional spread of contamination from a site.
Plume-Edge	Downgradient or Crossgradient	Plume-edge wells are located immediately downgradient or crossgradient of a plume and are used to track plume movement by flow, diffusion, or dispersion. Wells designated as plume-edge wells may need to change as the plume size and shape change. These wells may be part of a remedial system.
In-Plume	Downgradient	In-plume wells are located both vertically and horizontally within the known extent of contamination. These wells are used to track concentration changes over time. These wells may also serve as extraction wells for a remedial system.
Downgradient	Downgradient	Downgradient wells are located in the direction of groundwater flow from the source of contamination. Downgradient wells are used to track the concentration and movement of contaminants from a site. In-plume, plume-edge, point-of-compliance, and sentinel wells may all be downgradient wells.
Point-of-Compliance	Downgradient	Point-of-compliance wells are generally defined by an installation's RCRA or other permit, and are often located at the site or installation boundary. These wells are used to ensure that contamination is not migrating off site or affecting a sensitive receptor (see also "Sentinel" well).
Sentinel	Downgradient	Sentinel wells are positioned downgradient of the contamination and upgradient of some sensitive receptor, such as a drinking water source. Sentinel wells must be screened at an interval appropriate to what they are protecting.
Off-Base	Anywhere off base	Off-base wells may be installed and monitored in response to concerns from neighboring communities.

The next step is to evaluate the wells that currently exist on and around the site. In most cases, the design of a groundwater monitoring program will follow some degree of investigation, during which some monitoring points were installed. By nature, investigation studies are designed to determine where and how much contamination exists, the location of potential sources and hotspots, what direction a plume may be moving, and what contaminants are present in groundwater at the site. Answering these questions usually results in the installation of many more monitoring wells than are typically necessary for a well-designed monitoring program. In general, monitoring points should be chosen (or installed) with the following objectives in mind:

- Monitoring wells should be placed so that you can obtain background levels of contaminants of concern (COCs).
- Monitoring wells should be located and screened to bound the horizontal and vertical extent of contaminant plumes.
- Monitoring wells should be located so that bulk movement of the plume can be assessed. Sampling frequency and placement of in-plume and plume-edge wells will vary depending upon site-specific factors that affect contaminant transport.
- Monitoring wells should be placed in locations that provide feedback on performance of both active and passive remedial measures.

Where applicable and feasible, source areas or hotspots should be monitored to assess whether a source zone is still feeding the plume in question. Your design may also include monitoring extraction or treatment wells to track performance of a remedial system.

It is important to design flexibility into your monitoring network to allow for continual reassessment of program needs. You may need extra wells for: (1) accurately determining groundwater levels and flow direction at your site; (2) later monitoring as the plume size and shape change; and (3) contingency, in the case of damage to program wells.

In evaluating placement of monitoring wells, groundwater flow calculations may provide insight into where contamination is likely to leave a site, or how potential off-site hydraulic influences such as a pumping well might change future groundwater gradients at a site. Lateral spreading of a plume by hydrodynamic dispersion could also be approximated with more sophisticated calculations. These findings could have implications in determining the number and location of corrective action observation wells and/or POC wells. The application of groundwater flow calculations and more complex modeling is discussed in Section 9.2.

3.2 Optimizing the Monitoring Network

On an annual basis, you should reevaluate the objectives of the groundwater monitoring program as discussed in Section 2.3. If the value of the information provided by a monitoring point does not justify the cost of collecting and analyzing the samples, then it may be appropriate to eliminate it from the monitoring network. However, as discussed in Section 3.1, elimination of monitoring points must be conducted while keeping regulatory and community concerns in mind.

Example*: MCB Camp Lejeune regularly analyzes groundwater monitoring data, performs trend analysis, and contours the data to make recommendations for monitoring point reductions. The monitoring contractor is tasked with making these types of recommendations as part of their regular reporting process.*

3.2.1 Decision Criteria

Decision criteria are an important tool for optimizing a monitoring program. Decision criteria set predetermined requirements for deciding when an action will take place. Ultimately, decision criteria will provide the mechanism for ending the monitoring program at a site. Table 3-2 presents some example decision criteria as they relate to specific site objectives.

If decision criteria have already been established for eliminating monitoring points at your site, your annual review should include determining if any of the decision criteria have been met. If decision criteria have not been established, create some based on monitoring objectives.

Table 3-2. Example Decision Criteria for Eliminating Monitoring Points

Monitoring Program Objective	Example Decision Criteria	Data Evaluation Required
Track contaminant concentrations which are above some regulatory standard	Monitoring points that remain below the MCL for the COC for four consecutive sampling rounds will be eliminated from the monitoring program.	Depending on requirements, either a direct comparison of site data to MCLs or a statistical evaluation to determine which points are consistently and reliably below MCLs (see Section 9.1).
Identify contaminant trends	Monitoring points that are below the MCL for the COC and display no significant upward trend will be eliminated from the monitoring program.	Statistical evaluation of data to determine which points have concentrations with a significant upward trend, and which points have stabilized (see Section 9.1 and Appendix C).
Evaluate performance of a remedial system	Original plume-edge wells will be eliminated from the monitoring program when changes in plume size or shape make other wells more appropriate for plume-edge monitoring.	Use of a Geographic Information System (GIS) to track plume shape and size for all COCs (see Section 7 and 9.3).
Ensure that contaminants do not affect a drinking water source	The sentinel wells for supply well No. 1 will be monitored until it can be shown that contaminants from the site do not exceed 50% of the MCLs at any point for four consecutive sampling rounds.	Custom database queries to generate automatic reports of all contaminants exceeding MCLs, keeping a running tally for four sampling rounds (see Section 7).
Ensure that contaminants do not migrate off site	Point-of-compliance wells will be monitored until it can be shown that contaminant concentrations exceeding the MCL cannot migrate off site.	Conservative groundwater modeling to predict future concentrations at the installation boundary (see Section 9.2).

3.2.2 Statistical Tools for Optimization

There are several statistical tools that can be used to optimize the number of monitoring wells necessary to achieve your program goals. Geostatistics and temporal trend analysis are appropriate statistical methods for optimization. Geostatistical methods are used to evaluate the spatial pattern and correlation of contamination across a region, allowing you to observe which locations continue to have unacceptably high concentrations. Regression analyses can identify trends (typically linear trends) by determining if the regression model provides a good fit and by identifying how strongly concentrations correlate with time. Both trend analysis methods and geostatistical methods are discussed in more detail in Scenarios 6 and 7, respectively, of Appendix C.

3.2.3 Well Abandonment

After monitoring has been established at a site (and perhaps even before if a significant number of investigation phase monitoring wells exist), an evaluation of monitoring points for potential abandonment should be made. While it is important to ensure that an adequate number of monitoring points are maintained at your site to provide program flexibility (see Section 3.1), it is equally important to eliminate points that do not address program objectives and are unlikely to in the future. Proper well abandonment: (1) eliminates the physical hazard of the hole in the ground; (2) eliminates a conduit for migration of contamination; and (3) prevents hydrologic changes in the aquifer system, such as the changes in hydraulic head and the mixing of water between aquifers. Abandoning monitoring wells that are inappropriately screened, damaged, or dry also reduces well maintenance costs. W*ell abandonment must be conducted in accordance with applicable regulations, and must be reported to the proper authority. Figure 3-2 provides criteria for abandoning monitoring points.*

Example: *As part of the MCB Camp Lejeune monitoring program, regular inspections of monitoring wells are conducted. Wells that are in deteriorating condition are then recommended for proper abandonment to prevent further contamination of the groundwater and reduce monitoring well maintenance costs.*

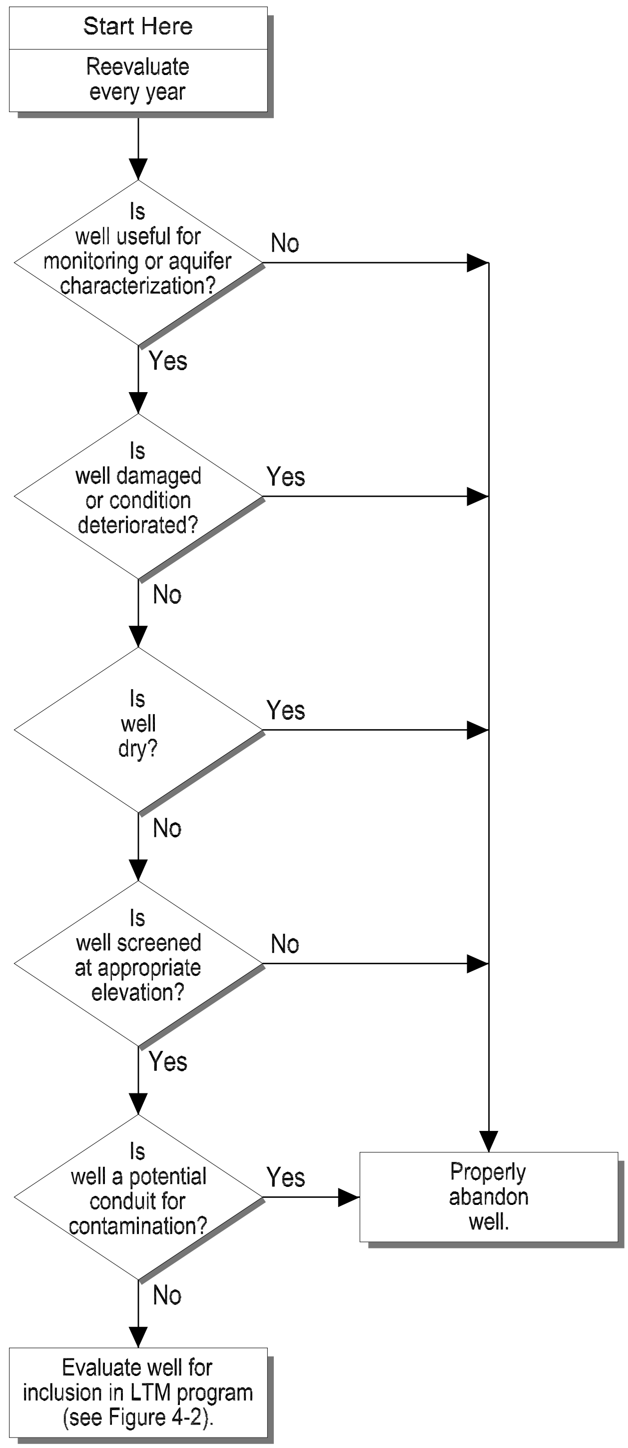


Figure 3-2. Decision Criteria for Abandoning Monitoring Wells

4.0 How Often Should I Monitor? For How Long?

Content: *This section describes tools you can use to support decisions regarding monitoring frequency and duration, including:*

- *Decision criteria and diagrams;*
- *Groundwater flow calculations (see also Section 9.2);*
- *Trend analysis; and*
- *Statistical tools (see also Section 9.1).*

4.1 Determining Appropriate Monitoring Frequency and Duration

4.1.1 General Approach

When starting a new monitoring program, it is often a good idea to collect four rounds of quarterly data, particularly if investigation data for your site are limited (e.g., from one round of sampling, or from only one time of year) or obsolete (e.g., more than three years old). Four quarters of analytical and water level data will help establish the presence of any temporal (such as seasonal) and spatial variability. In addition, four data points are often considered the minimum for conducting any sort of statistical evaluation. *It is essential that all monitoring data be collected using the same sampling and analytical methods to ensure comparability. Your GMP should be used to document these methods (see Sections 2.2 and 8).* If a recent, well-designed site investigation has been conducted, starting a monitoring program with semiannual or even annual monitoring may be more appropriate.

Following the first year of quarterly data collection, monitoring frequency may be reduced as appropriate, following decision criteria built into the GMP. Specific decision criteria should be included for determining when monitoring may be discontinued at your site. A review period, most likely annual, should be specified in the GMP to periodically evaluate the potential for site closure based on monitoring data and closure decision criteria.

The purpose of a well should be taken into account when determining the sampling frequency. Downgradient, plume-edge wells generally require more frequent sampling than an upgradient or background well. Special purpose wells, such as sentinel wells, may need to be sampled often to safeguard human health. Likewise, POC wells may need to be sampled more frequently than on-site wells to help maintain good faith between your installation and neighboring communities. Table 4-1 gives examples of monitoring frequencies, based on the purpose of the wells.

Example: *Quarterly monitoring for the first year, along with a built-in annual review with state regulators, was recommended for the NWIRP Dallas monitoring program. Following a year of quarterly sampling, they could then seek a decrease in monitoring frequency, tailoring frequency to the function of the well. Whereas POC and corrective action observation wells were recommended for semiannual sampling, upgradient, background, and supplemental wells could be dropped to annual sampling. If approximately half the monitoring wells at the site were decreased to semiannual sampling, while the other half were decreased to annual sampling, over 60% of analytical costs could be saved in the second year of sampling. Based on analytical costs of $350/sample for 60 samples per round, an annual savings of $52,000 could be realized in analytical costs alone. Field labor costs would decrease from approximately $20,000 to $8000 annually, and mobilization and demobilization costs would be cut in half by eliminating two quarterly sampling rounds.*

Table 4-1. Example Monitoring Frequencies for Different Types of Wells

Well Type	First Year Frequency	Second Year Frequency	Third Year Frequency	Considerations
Background	Quarterly	Annually	Annually–	On-site migration of contaminants; naturally-occurring compounds
Upgradient	Quarterly	Annually	Annually–	On-site migration of contaminants
Downgradient	Quarterly	Semiannually	Annually	Migration of site contaminants
Crossgradient	Quarterly	Semiannually	Semiannually	Dispersion of site contaminants
In-Plume	Quarterly	Semiannually	Annually	Remediation progress, if applicable
Plume-Edge	Quarterly	Semiannually	Semiannually	Plume movement
Point-of-Compliance	Quarterly	Semiannually	Semiannually	Maintaining community relations
Sentinel	Quarterly	Quarterly	Quarterly	Safeguarding human health
Off-Base	Quarterly	Semiannually	Annually	Maintaining community relations

Note: Annually– = Annually or less frequent (e.g., every 2 years)

4.1.2 Flow Calculations to Determine Monitoring Frequency and Duration

Calculations can be used to estimate the rate of groundwater flow at a site. Although the rate of contaminant movement is usually not as fast as groundwater movement (see Section 9.2), the use of simple flow equations can provide a conservative estimate of how long it will take contamination to reach a particular point, such as the installation boundary or a supply well. This information can then be used to determine an appropriate sampling frequency and duration.

The following example describes how basic flow rate information can be used to determine the frequency of monitoring at a given point: Benzene from a fuel spill site is estimated to travel at the same rate as groundwater, which is modeled to move at 7 feet per year. The frequency of monitoring at a given point should be related to the rate of contaminant movement. For instance, it may be necessary to sample wells close to the contamination on a quarterly basis. However, it is not reasonable to sample a clean well located 350 feet downgradient from known contamination with the same frequency because it will take fifty years for the benzene to reach the well.

Additionally, if contamination isn’t detected in downgradient wells within a reasonable timeframe based on flow calculation results, it may be determined that contamination will not reach the site boundary and monitoring may be discontinued. An example exit criterion for such a case would be any well where contamination is not detected over the course of three travel times (i.e., the estimated or modeled time that it would take for the contaminant to travel from the source area to the well) would no longer be monitored.

4.1.3 Trend Analysis and Statistics to Optimize Monitoring Frequency and Duration

By identifying data trends at your site, you will be able to propose the most appropriate sampling frequency. If a simple concentration versus time plot of the data indicates that concentration trends in target analytes are not changing rapidly, monitoring may be decreased to semiannually. Following a year of semiannual data collection, a similar analysis can be made to see if a reduction to annual monitoring might be implemented. Figure 4-1 shows an example of a time-series plot that may be used for this type of analysis.

If the trends of concentration over time are not clear, it may be helpful to conduct temporal trend analysis using the statistical methods outlined in Appendix C. Temporal trend analysis methods typically include plotting a well's chemical concentrations as a function of time and identifying a trend by using the Mann-Kendall trend test or a regression analysis. Trend analysis methods are discussed in more detail in Scenarios 6 and 7 of Appendix C.

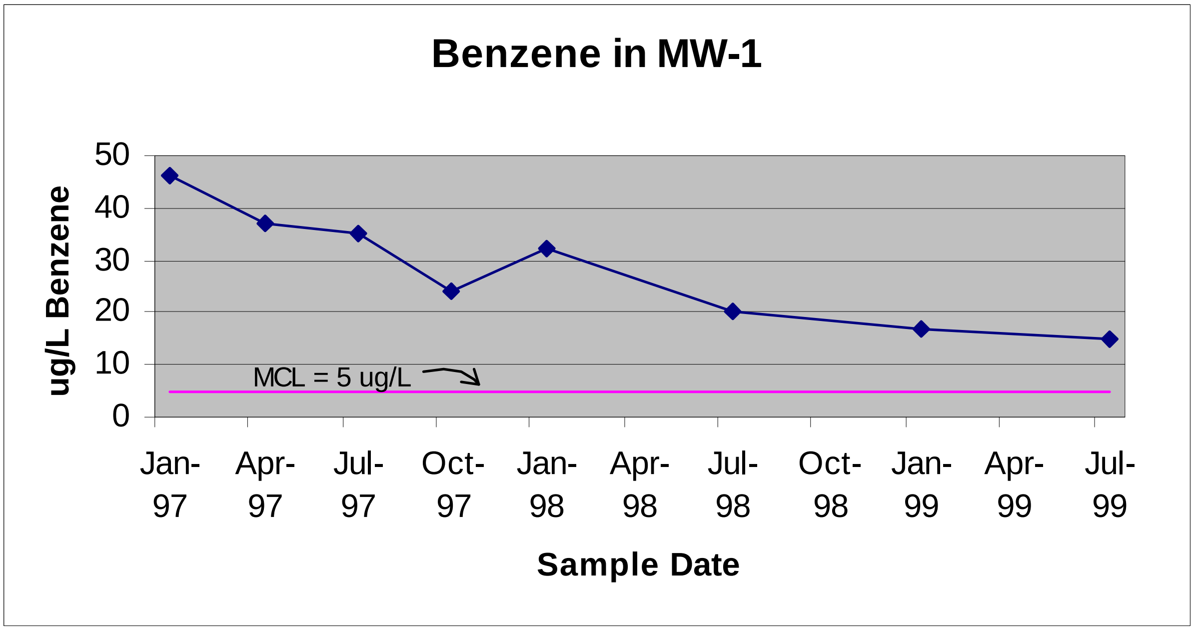


Figure 4-1. Example Time-Series Plot

Trend analysis or statistics may also be used to support a decision to stop monitoring at a well or a site if contaminant concentrations are found to be stable over a long period of time. It may be possible to show statistically that there is not a significant difference between upgradient and downgradient concentrations of target analytes at a site. In this case, it may also be appropriate to stop monitoring at the site. Scenario 8 of Appendix C provides more details about this type of comparison.

Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance (EPA, 1989) offers a comprehensive reference for statistical applications at monitoring sites.

4.1.4 Decision Criteria for Reducing Frequency and Duration

After each sampling event, or at least annually, you should reevaluate the objectives of the groundwater monitoring program (see Section 2.3). Determine if any of the decision criteria for reducing the frequency or duration of monitoring at a site or individual monitoring point have been met. Table 4-2 presents example decision criteria for reducing monitoring frequency and duration. Figure 4-2 shows an example decision diagram for determining monitoring frequency of wells at a site (note that this is an example and your decision criteria may be different depending on site-specific characteristics).

Table 4-2. Example Decision Criteria for Reducing Monitoring Frequency and Duration

Monitoring Program Objective	Example Decision Criteria	Data Evaluation Required
Frequency		
Identify contaminant trends	Monitoring points that exceed the MCLs but do not display a significant upward trend will be reduced to semiannual sampling.	Time trends or statistical evaluation of data to determine which points have concentrations with a significant upward trend (see Section 9.1).
Evaluate performance of a remedial system	Once system performance has reached a plateau, site monitoring will be decreased to annually.	System performance data (pounds removed per unit time) or statistical evaluation of analytical data to determine which points have concentrations with a significant upward trend (see Section 9.1).
Duration		
Track contaminant concentrations which are above some regulatory standard	Following three consecutive rounds of all COCs detected at less than the maximum contaminant levels (MCLs), monitoring at the site will be stopped.	Custom database queries to generate automatic reports of all contaminants exceeding MCLs, keeping a running tally for three sampling rounds (see Section 7).
Ensure that contaminants do not migrate off site	If COC concentrations at POC wells do not exhibit concentrations above the MCL within 5 years and exhibit stable or decreasing trends, monitoring at the site will be stopped.	Conservative groundwater flow calculations to predict contaminant transport rates and statistical analysis to confirm contaminant trends at the installation boundary (see Section 9.2).

4.2 Considerations for Optimizing Monitoring Duration and Frequency

Decreasing the number of samples through reductions in sampling duration and/or frequency is an important aspect of optimizing an existing groundwater monitoring program. Reducing monitoring frequency by 50% will decrease sampling labor, analysis, validation, and reporting costs by a like percentage. The general approach to this type of optimization is essentially the same as presented for designing a new program (see Section 4.1). The important difference is that existing programs may not have pre-approved decision criteria for optimizing frequency and duration. Section 8 of this guidance document offers some tips on gaining regulator approval. The statistical methods described in Section 9.1 and Appendix C will also help support decisions to optimize monitoring frequency and duration.

Example: *Monitoring program data are reviewed annually at MCB Camp Lejeune to determine where reductions in sampling frequency can be made. The entire groundwater monitoring program has been reduced to semiannual or less frequent monitoring. MCB Camp Lejeune also has approved decision criteria in place for removing sites from their monitoring program. Using these decision criteria, they have gained approval for halting monitoring at one site and anticipate removing three more sites.*

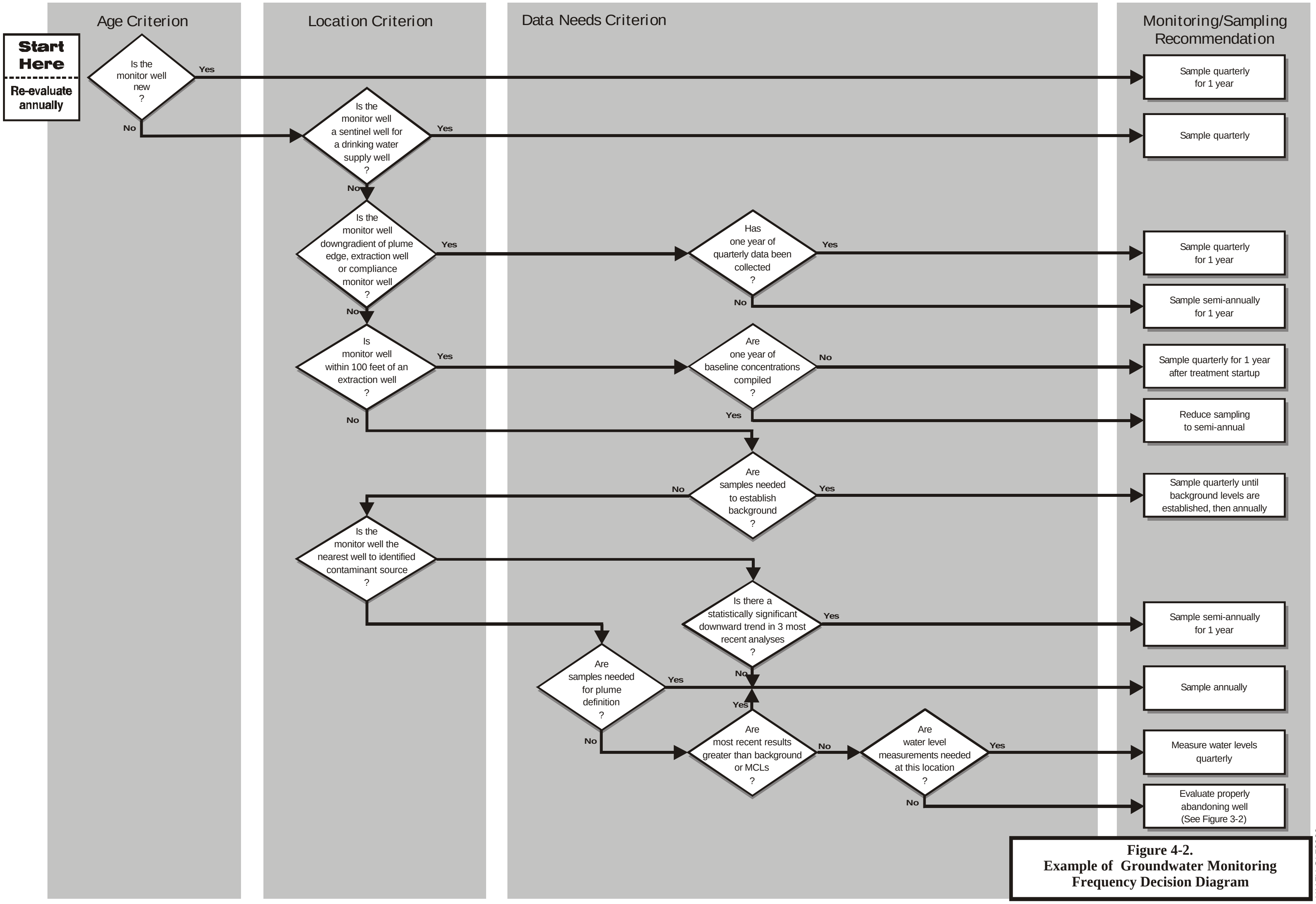


Figure 4-2.
Example of Groundwater Monitoring Frequency Decision Diagram

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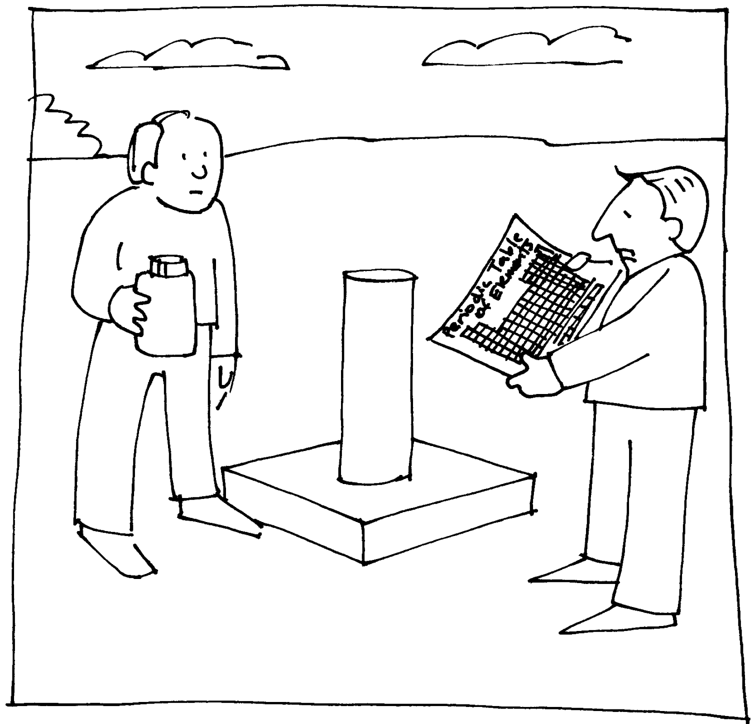
5.0 What Contaminants Do I Need to Monitor?

Content: *This section will help you focus on the types of data that you need to ensure that the objectives of your monitoring program are met and the data are of the appropriate quality. Tools that can help you determine your analytical data and QA/QC needs include:*

- *Historical data;*
- *Statistical tools (see Section 9.1);*
- *Decision criteria; and*
- *Existing Navy and regulatory guidance.*



OK... here's what we're sampling for...

5.1 Streamlining the Analyte List

Since analytical costs make up a significant portion of monitoring program expenses, streamlining the analytical approach is a viable way to cut overall monitoring program costs. Minimizing the number of analytes at a site and ensuring there is no overlap in analytical methods are examples of ways to streamline the analytical program.

5.1.1 Identifying Analytes for Initial Monitoring

Including only the necessary compounds in your site's analyte list not only reduces analytical costs, it reduces data management, validation, interpretation, and reporting costs. Even if receiving data for the total analyte list of a given method is no more costly than receiving data for only certain analytes, it is beneficial to eliminate the extra analytes. Including only the analytes of interest results in clearer, more concise reports.

To determine which contaminants to monitor during the initial rounds of the groundwater monitoring program you should review the following information:

- Site history (for example: landfill, refueling station, or vehicle maintenance);
- Historical analytical data for both soils and groundwater at the site (e.g., data from PA/SI or RI/FS).
- Historical analytical data from upgradient sites that may impact groundwater quality;
- Regulatory criteria applicable to groundwater monitoring at the site.
- Background concentrations of potential target analytes in uncontaminated soil, water, and other pertinent media (for inorganic compounds only); and
- Results of previous baseline risk assessments performed at the site.

Reviewing historical practices at the site will enable you to focus sampling efforts on those contaminants needed to demonstrate cleanup progress. For example, the groundwater underlying a refueling station may be contaminated with fuel components but would probably not require analyses for pesticides and polychlorinated biphenyls (PCBs). However, samples underlying an unrestricted landfill may require analyses for a wide array of compounds.

Historical analytical data, if available, are better tools than site history for determining which analytes to monitor initially. Comparing historical data to regulatory criteria, or background or upgradient data, will help identify those contaminants that need to be monitored because they approach or exceed some standard. Historical data, if collected regularly over a period of time, may also be used to determine if any of the contaminants have historically exhibited increasing trends, indicating a potential active source at the site. Section 9.1 and Appendix C discuss statistical tools that can be used to differentiate between up- and downgradient concentrations (or site and background concentrations), and identify contaminants with increasing trends.

If a risk assessment was conducted for the site, the results will be valuable in determining which contaminants to monitor. If any of the site contaminants were found to pose a risk to human health and/or the environment, they should be included in the initial monitoring program. Contaminants that were found to pose no risk may have a strong basis for elimination from the program.

5.1.2 Modifying the Analyte List

As monitoring progresses, you may be able to reduce the list of analytes for a site to focus only on COCs and associated degradation products. For example, groundwater contaminated with tetrachloroethene, a solvent historically used to degrease and clean metal, may also be analyzed for degradation products trichloroethene, dichlorethene(s), and vinyl chloride. However, analyses for other volatile organic compounds (VOCs) may no longer be necessary. To identify other parameters that may be eliminated, you should review the data to identify those that have not been detected above the reporting limit (i.e., all results not detected or detected only at concentrations indistinguishable from laboratory blanks) in the first four quarters of sampling.

With regulator approval, this list may be further reduced by evaluating the detected analytes against regulatory standards. Metals may be eliminated from the analyte list based on a comparison to background levels, determined by collecting and analyzing groundwater samples from uncontaminated areas of the installation using methods that achieve representative analytical results for metals in groundwater (i.e., filtered or non-turbid samples) (see Section 6.0). The background data can then be used to determine which contaminants are present at concentrations significantly above expected background concentrations, and therefore require continued monitoring (see Section 9.1 and Appendix C).

Another approach you can take at a monitoring site that has the potential for several different types of contamination is to use faster-moving contaminants, such as VOCs, as indicator species. For example, consider the case of an unrestricted landfill with the potential for almost any type of contaminant. To date, nothing significant has been detected downgradient of the site boundaries, but the state wants groundwater monitoring for a minimum of five years before closing the site out. Instead of analyzing for a complete list of potential site contaminants, you could propose monitoring only for the fastest migrating contaminants, or indicator species, expected to result from site activities. Monitoring of these indicator species can continue until the five-year monitoring period has elapsed. However, if indicator species are detected within the five years, analysis of other potential site contaminants should begin.

5.1.3 Decision Criteria to Evaluate Analytes for the Monitoring Program

After each sampling event, or at least annually, you should reevaluate the objectives of the groundwater monitoring program (see Section 2.3). The specific decision criteria for reducing the number of analytes being monitored should be tied to the objectives established for the groundwater monitoring program.

Table 5-1 presents example decision criteria for reducing the number of analytes as your monitoring program progresses.

Table 5-1. Example Decision Criteria for Reducing Analytes

Monitoring Program Objective	Example Decision Criteria	Data Evaluation Required
Track contaminant concentrations which are above some regulatory standard	Analytes that remain below the MCL for four consecutive sampling rounds will be eliminated from the monitoring program.	Depending on requirements, a one to one comparison or a statistical evaluation to determine which points are consistently and reliably below regulatory standards (see Section 9.1).
Identify continuing sources	Analytes that are below the MCL and display no significant upward trend will be eliminated from the monitoring program.	Statistical evaluation of data to determine which analytes display a significant upward trend, and which analytes have stabilized (see Section 9.1).
Evaluate performance of a remedial system	Any contaminant that displays a decreasing trend and then has two quarters of data below remediation goals will be eliminated from the monitoring program.	Statistical evaluation of data to determine which analytes display a significant downward trend, and have stabilized below remediation goals (see Section 9.1).
Ensure that contaminants do not affect a drinking water source	Any contaminants that do not exceed 50% of the MCLs for four consecutive sampling rounds will be eliminated from the monitoring program.	Custom database queries to generate automatic reports of all contaminants exceeding MCLs, keeping a running tally for four sampling rounds (see Section 7).

Example: *Following historical sampling that consisted of total compound list (TCL) organics, total analyte list (TAL) metals, and hexavalent chromium at NWIRP Dallas, the sampling contractor proposed including only the COCs (VOCs, metals, and hexavalent chromium) in the monitoring program. This proposed analyte list represents a significant cost savings compared with the original analyte list: $351/sample versus $811/sample, or a 57% decrease in the analytical budget.*

In addition to eliminating entire methods (in this case, methods for SVOCs and pesticides/PCBs), it was recommended that the contractor consider the elimination of individual compounds within methods. Although this does not always result in significant analytical cost savings, it does save data management, validation, and reporting costs. A review of the site-wide sampling round data that were collected in 1994, 1995, and 1997 was conducted to determine whether further decreases could be made to the analyte lists for VOCs and metals. VOCs that have not been detected above reporting limits and metals that have never exceeded background values were identified for elimination from the monitoring program.

On the basis of this analysis, the following ten VOCs were proposed for elimination from the monitoring program at NWIRP Dallas:

- *1,1,2,2-Tetrachloroethane;*
- *1,3-Dichlorobenzene;*
- *1,4-Dichlorobenzene;*
- *Bromoform;*
- *Bromomethane;*
- *Dibromochloromethane;*
- *m&p Xylenes;*
- *Styrene;*
- *trans-1,3-Dichloropropene; and*
- *Vinyl Acetate.*

Also on the basis of this analysis, few metals were proposed for elimination from the upcoming monitoring program at NWIRP Dallas. Only sodium, magnesium, and manganese had never exceeded the background upper tolerance limits for the site. However, in more recent sampling rounds, the use of micropurging had decreased the concentrations of metals in groundwater samples. Looking only at data for 1997 samples, which were collected using micropurging techniques, it appeared that calcium, copper, and iron could also be eliminated from the program on the basis that they did not exceed the expected background values for the site.

5.2 What QA/QC Procedures are Necessary for a Monitoring Program?

The Navy Installation Restoration Chemical Data Quality Manual (IR CDQM) (NFESC, September 1999) provides some general information on data quality issues related to the IRP, but does not specify exact QC sample collection rates for Navy sampling programs. The following subsections offer some generally accepted approaches for ensuring that QC sample and data validation rates are appropriate.

5.2.1 Field QC Samples

Quality control for field samples is measured by the results of field duplicates, field blanks, equipment blanks, and trip blanks. These field QC samples are defined as follows:

- Field duplicates are two samples of the same matrix collected from the same location at the same time, following identical procedures. Field duplicates are analyzed to provide an overall measure of the precision of the sample collection and analytical process.
- Field blanks, sometimes referred to as ambient blanks, are typically samples of reagent-grade water that are prepared at the site and handled in the same way as field samples. These samples are not collected using field equipment, but are poured directly into the sampling container. These samples are then stored, shipped, and analyzed in the same way as the field samples. Field blanks are analyzed to provide a measure of the degree of ambient contamination resulting from conditions during sample collection, storage, shipment, and analysis.
- Equipment blanks consist of reagent-grade water that has been passed through or over decontaminated sampling equipment. These blanks should be handled in the same way as field samples. The use of disposable equipment does not eliminate the need for equipment blanks. Equipment blanks are analyzed to assess the adequacy of the decontamination process, but it also incorporates contaminant effects from sample handling, storage, shipping, and analysis.
- Trip blanks are typically 40 ml vials filled with reagent-grade water that are prepared in the laboratory, shipped to the field, and are returned unopened along with the field samples. Trip blanks are used to assess the potential for cross-contamination by VOCs during shipping, storage, and analysis of samples.

The recommended frequencies for field QC sample collection vary from region to region within the EPA and from state to state. Field QC samples are not required; however, they can provide valuable and useful information regarding sampling procedures. Field QC samples should always be considered when planning a project; however, they should not be collected simply for the sake of QC. If, for example, a field duplicate will not provide useful information or is not needed to meet project objectives, then it is probably not worth the additional time and expense. Therefore, the preferred approach is to ensure that the program design includes the types and numbers of QC samples necessary to meet the project DQOs, and that the QC requirements are revisited as monitoring progresses.

It is important to document the rate of field QC sampling in the GMP, as well as decision criteria for reducing the rate as monitoring progresses. QC data should be reviewed regularly as a way to potentially reduce analytical costs for an existing monitoring program, as long as DQOs can still be met and regulatory approval can be obtained. Table 5-2 gives examples of beginning and optimized field QC frequency rates.

Table 5-2. Example Field QC Frequencies

QC Sample	Example Start Frequency	Example Optimization Approach
Field Duplicates	Collect field duplicates at a rate of 10% at the start of monitoring. Round up or down depending upon how close you are to the next whole sample. For instance, a site with 12 wells may need only one field duplicate each round, whereas a program with 19 wells could start out with two duplicates.	After monitoring has been conducted for four or more quarters, determine if groundwater at the site tends to be highly variable. If program DQOs can continue to be met with a reduced field duplicate frequency, petition to decrease field duplicates to 5% of the normal sample total.
Field Blanks	Field blanks, if required, will be collected at a rate of one field blank per site per sampling event. A field blank is recommended for each day that sampling is conducted in windy or dusty conditions.	If field blanks come back without significant contamination following a year of quarterly data, collect only if sampling is conducted under windy or dusty conditions. If possible, avoid sampling under these conditions, or in the area of motorized equipment, so that field blanks can be eliminated.
Equipment Blanks	One equipment blank will be collected per day per sampling event.	Use dedicated equipment to the extent possible. Following submittal of initial equipment blanks for new equipment, no additional equipment blanks should be needed.
Trip Blanks	One trip blank should be provided for every discrete shipping container (e.g., cooler or box) that transports a sample for determination of VOCs.	Ship all VOC samples in the same cooler. Ship samples every other day if sample hold times will not be compromised.

Example: *An evaluation of the types and numbers of the QC samples collected for the Naval Air Station (NAS) Patuxent River landfill monitoring program suggested that some cost savings could be realized without negatively affecting the quality of the program. Field duplicates were being sampled at a rate of 10% on a total of 12 normal groundwater samples. This was being rounded up, for a total of two field duplicates each quarter. Following four quarters of sampling, it was recommended that they reduce field duplicates to one per quarter.*

It was also recommended that trip blanks, which are submitted with each shipment containing samples for volatile parameters, be decreased by reducing the number of coolers packed with these types of samples (e.g., shipping every other day, putting all VOC samples together in one cooler, etc.). Table 5-3 shows the recommended reductions in QC sample collection for the 2-day, 12-well sampling program. Applying these cost-saving measures to a quarterly program would result in almost $8000 in cost avoidance annually.

Table 5-3. Example Groundwater QC Sample Reductions per Sampling Round

Analyte	Number of Normal Samples	Field Duplicates	Equipment Blanks	Trip Blanks[a]	Total Samples
TCL Organics	12	2 ➡ 1	2 ➡ 1	2 ➡ 1	18 ➡ 15
TAL Metals	12	2 ➡ 1	2 ➡ 1	N/A	16 ➡ 14

[a]VOCs only
➡ denotes the recommended reduction.

5.2.2 Data Review and Validation

Like QC sample requirements, data review and validation should be geared toward achieving the DQOs and can be changed as the monitoring program progresses. Also as with QC sample requirements, data validation rates and decision criteria for reducing them should be documented in the approved GMP.

Appendix H of the IR CDQM (NFESC, September 1999) provides Navy requirements and guidance for data review and validation. This document defines data review as a "systematic approach for the review of laboratory data," and data validation as a "thorough assessment of data and supporting QC documentation without making any assumption to the quality of the data provided."

In data review, only the sample results and limited project documentation are typically reviewed. The end user of the data is responsible for conducting a 100 percent review of laboratory data for completeness. This type of review is referred to as a summary or low level review and includes the following elements:

- Completeness;
- Holding times;
- Chain of custody;
- Method and reporting limits;
- Dilution factors/concentration units;
- Preparation/analysis methods;
- Matrix spike results (if provided); and
- Surrogate recoveries (if provided).

Data validation is more thorough and involves an evaluation of reported data, raw data, supporting information, and project documentation to determine if the data are of sufficient quality to satisfy the project DQOs. The elements of data validation may be specified by project or program guidance, or may be taken from the IR CDQM in the absence of such guidance. The data validation rate may be 100% for a project providing input for high-risk decisions, or may be very limited for routine monitoring data. The validation process and frequency, as well as decision criteria for reducing them, must be based on the project DQOs and documented in the GMP.

6.0 How Should I Collect the Samples?

Content: *Sample collection is one of the most important steps of your monitoring program. Unless you properly collect, handle, and document your sample, it is just a bottle of water. This section presents tools you can use to improve sample quality while reducing program costs. These tools include:*

- *Low-flow purging;*
- *Dedicated equipment; and*
- *Diffusion samplers.*

6.1 Sampling Techniques

6.1.1 Low-Flow Purging

Low-flow purging, or "micropurging," is a widely accepted purging and sampling technique that has many benefits, including:

- Improved sample quality and representativeness (i.e., lower turbidity);
- Decreased purging volumes and time;
- Decreased investigation-derived waste (IDW) handling; and
- Less wear and tear on your wells (via overdevelopment).

But we've always done it this way...

Another benefit that may result from low-flow purging is a decrease in metal concentrations associated with high sample turbidity. Metal concentrations may be decreased by two orders of magnitude compared with traditional purging methods. If metals are among the contaminants of concern at your site, it is strongly recommended that you consider using low-flow purging techniques.

The goal of this technique is to eliminate vertical movement of groundwater within the well casing during purging. In doing this, the well may be purged from one small section of the screened interval, without mixing stagnant casing water and fresh formation water. Therefore, purge times and volumes are significantly decreased. Wells are purged only until water quality parameters such as pH, conductivity, temperature, and dissolved oxygen, have stabilized. This is typically accomplished after just a few liters of water have been purged from the well.

Before implementing low-flow purging, it is essential to determine if this technique is appropriate for your site. The primary question to ask is “Do all of the wells that are essential to my monitoring program have adequate recharge rates to support low-flow purging?” If it is not possible to maintain drawdown at less than 0.3 ft at pumping rates of between 0.1 and 0.5 L/min, your site is probably not a candidate for low-flow purging. In this case, traditional purging techniques (i.e., at least three well volumes *and* stabilized water quality parameters) should be used. In virtually all other situations, low-flow purging will result in better quality samples, lower labor costs, less IDW, and less wear and tear on your well.

Although dedicated bladder pumps are the preferred equipment for successfully applying low-flow purging (Puls and Barcelona, 1995) and may save money in the long run, a considerable up-front capital expenditure is required. If a dedicated system is not deemed feasible, but low-flow purging is appropriate for the site, renting two nondedicated pumps should be considered. With two pumps, one can be placed in a well and allowed to stabilize while purging, sampling, and decontamination is taking place at another monitoring point.

Example 1: *During a pre-monitoring program sampling round conducted at NWIRP Dallas, micropurging techniques were used in a successful attempt to reduce high turbidity in samples and consequently achieve representative results for metals in the groundwater. A low flow rate (approx. 100 to 300 ml/min) and peristaltic pumps with dedicated Teflon tubing were used for the micropurging. This approach will be built into the design of NWIRP Dallas' monitoring program, and is consistent with the purging guidelines set forth by the TNRCC.*

Example 2: *At a landfill site at NAS Patuxent River, monitoring wells were being purged and sampled using low-flow rates with non-dedicated equipment. However, three full well volumes were being purged. As part of the case study recommendations, the cost of installing a dedicated low-flow purging system was estimated at $1000/well, plus $1000 for a pump controller that could be moved from well to well. Based on a nine-well monitoring network, the total cost of the system was approximately $10,000. If sampling labor was decreased by 40% each round by switching to strictly parameter-based purging criteria, an annual savings of $3200 could be realized, based on five 8-hour person-days per quarter at $50/hour. The use of dedicated equipment would also result in the elimination of two equipment blanks per quarter, at approximately $1000 per sample in analytical costs, for another $8000 in annual savings.*

Also at this site, samples were being collected and analyzed for total and dissolved metals. Dissolved metals are generally measured on samples that have been filtered to 0.45 microns, which is the operable definition of dissolved. This is an arbitrary cutoff and does not necessarily represent the chemical conditions of the aquifer. A total metals analysis on a high quality (low turbidity) sample is more likely to represent true aquifer conditions. At this site, dissolved metals results appear to be within the same order of magnitude as the total results, and adoption of micropurging techniques was recommended to further reduce the difference and increase sample representativeness. Eliminating the need to analyze dissolved metals represented a savings of $9000 per year in analytical and data validation costs.

At this rate, it was estimated that a dedicated low-flow pump system should pay for itself in one year of quarterly sampling. This conservative estimate did not include cost savings associated with data management, purge water handling (not a significant cost at the landfill), travel, reporting, etc. When groundwater monitoring has been terminated, the dedicated pumps could be decontaminated and reinstalled in other wells or at other sites in order to increase the economy of the program.

6.1.2 Diffusion Samplers for VOCs

Diffusion sampling technology is currently receiving attention as an inexpensive, yet accurate, method to collect VOC samples from monitoring wells. Diffusion samplers are basically plastic bags (low-density polyethylene [LDPE]) filled with deionized (DI) water. The LDPE bag, or cell, acts as a semipermeable membrane that allows VOCs to diffuse into the DI water over time. Once lowered to within the screened interval of the well, the diffusion samplers need two weeks to equilibrate with the water in the aquifer with respect to VOCs. Diffusion sampling offers many of the same benefits as low-flow purging, with the potential to save more money on equipment costs for programs where VOCs are the only COCs. Some of the advantages of diffusion sampling include (EPA, 1997):

- Good sample quality;
- Virtually no purge water to deal with;
- Samples representative of the exact horizontal and vertical location;
- Less wear and tear on the monitoring wells; and

- Efficacy independent of formation texture (e.g., sand, silt, clay, etc.).

Diffusion sampling of VOCs is well suited for wells that have negligible mixing between water within the screened and unscreened intervals of the casing. As such, the suitability of diffusion samplers should always be confirmed at the onset of the sampling program by comparing results of samples collected in the diffusion samplers to those collected by flow-extraction methods. Mixing of water within the well can result in lower detected concentrations of VOCs for the samples collected from diffusion samplers due to volatilization within the well bore.

Currently, the DON, United States Air Force (USAF), United States Geological Survey (USGS), and Interstate Technology and Regulatory Cooperation (ITRC) are working together on a protocol for diffusion samplers. This protocol is expected to be available in spring of 2000.

6.1.3 Dedicated Sampling Equipment

Independent of purging and sampling techniques, dedicated sampling equipment offers sample quality and cost benefits. Although dedicated sampling equipment is often more expensive than reusable equipment, you may realize significant cost avoidance by:

- Eliminating labor costs associated with equipment decontamination;
- Eliminating labor and analytical costs associated with collecting and analyzing equipment blanks; and
- Eliminating costs associated with handling and disposing of decontamination wastes.

In addition, you will eliminate the potential for cross contamination of samples, and associated resampling.

6.2 Considerations for Optimizing Your Sampling Program

If you do not have approved decision criteria in place, you will need to work with your regulatory agencies to optimize an existing field sampling program. You may need to provide sound technical information to ensure your regulators are comfortable with the proposed optimization methods or techniques. Low-flow purging and sampling have been accepted techniques for several years and there is technical literature available if necessary. Passive diffusion sampling techniques have recently gained popularity, but the USGS and other agencies have been developing and using these techniques for several years. There are technical papers available and a protocol for the proper use of diffusion samplers is currently under development. If you need more information or support with these or other techniques, contact the technical support representative at your Engineering Field Division (EFD), Engineering Field Activity (EFA), or NFESC.

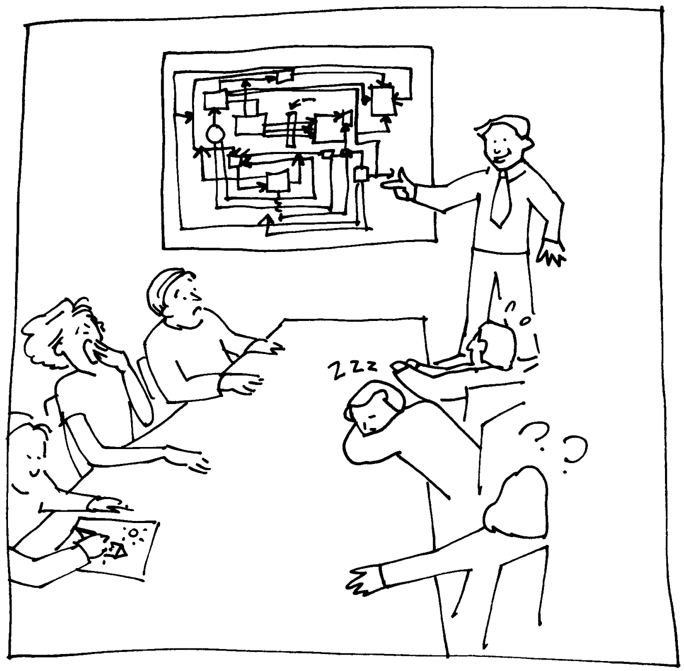
7.0 How Do I Evaluate and Present My Data So It's Easy to Understand?

Content: *This section looks at several examples of specific tools to evaluate data, streamline reports, and prepare effective presentations. These tools include:*

- *Statistical and geostatistical tools (see Section 9.1);*
- *Graphical and tabular formats;*
- *Geographic information systems (see Section 9.3); and*
- *Custom databases.*

7.1 Identifying Data Evaluation and Presentation Tools

It can be difficult to evaluate monitoring data kept in a spreadsheet and even more difficult to try to present and explain it to others. Data evaluation tools can help you clearly summarize your monitoring data, compare against decision criteria, and draw appropriate conclusions about the data. Data presentation tools help you ensure that your data interpretation and evaluation of decision criteria are clear and logical to others.



It's really quite simple!

7.1.1 Statistical Data Evaluation Methods

Statistical techniques provide an objective methodology for making specific decisions based on the data. Because statistical tests can be used to quantify uncertainty in data, they provide you with answers to both "What are the data telling me?" and "How certain can I be about the conclusions?" A wide range of statistical tools may be applied to groundwater monitoring, depending on the specific objectives of the program. In terms of project objectives, questions that these tools can address include:

- **How can I test for a contaminant trend in a well or group of wells?** Statistical tools that can identify trends are the Mann-Kendall test or regression analysis.
- **How can I evaluate hydrogeological or contaminant data spatially and what do I gain from such an analysis?** Geostatistical tools that can evaluate data spatially (i.e., ways to identify spatial trends) are semivariogram plots and kriging methods.
- **How can I identify well concentrations that exceed regulatory standards?** Statistical tools that can address such an objective are individual comparisons (such as an upper tolerance limit) and one-sample means comparisons (such as a one-sample t-test).
- **How can I identify outliers or extreme concentrations?** Statistical tools that can identify outliers are box plots and an EPA outlier test.
- **How can I identify differences in concentrations between downgradient and upgradient wells or differences in concentrations between current baseline data?** Statistical tools that can identify differences between two sets of data are two-sample means comparisons (such as the two-sample t-test), individual comparisons (such as an upper tolerance limit), and the quantile test.

- **How can I identify differences in chemical concentrations among wells or identify differences in concentrations among multiple chemicals?** Statistical tools that can identify differences among multiple sets of data are analysis of variance (ANOVA) procedures, multiple comparison tests, and contrasts.
- **How can I determine the level of statistical certainty achieved by a statistical method?** The statistical methods themselves provide a means of identifying the power achieved by the statistical test.

A more detailed discussion of the tests described above is provided in Section 9.1. In addition, Engineering Field Division Southwest (SWDIV) and Engineering Field Activity West (EFAWEST) have prepared a guidance document for using statistics in the analysis of environmental background data (NAVFAC, September 1998).

Example: *As part of the monitoring program at NAS Brunswick, a geostatistical assessment was performed to evaluate the monitoring network. One of the objectives of the geostatistical assessment was to identify data gaps and surpluses within the groundwater plume. To accomplish this, ordinary kriging was performed using the GEO-EAS program. This technique allows for the identification of areas with high and low predictive confidence. Areas with low predictive confidence may need additional monitoring points, whereas areas with very high predictive confidence may be providing redundant data. As a result of the geostatistical analysis, NAS Brunswick determined that it could eliminate 19 monitoring wells from the network, but that five additional wells must be installed and sampled to fill data gaps.*

7.1.2 Graphical Formats

Graphical data visualization is a powerful technique that can be used to illuminate trends, data anomalies, or systematic patterns that would not otherwise be apparent. Many graphical formats can be used to provide quick assessments of concentration ranges, extreme concentrations, or potential trends such as plume locations and seasonal trends. With readily available software, many of these plots are simple to create and evaluate. Methods of displaying data in graphical format include the following:

- **Box plots** (Figure 7-1). These diagrams summarize the statistical distribution of the data in a graphical format. They are useful for showing average and extreme values.
- **Time or trend plots of concentrations** (see Figures 4-1 and 7-2). Concentrations can be plotted versus sampling date in order to visually assess trends, seasonal fluctuations, and anomalous values. It may be useful to include meaningful comparison values on such plots. For example, a line may be drawn across the plot at the MCL, or at the upgradient or baseline values.
- **Spatial maps of groundwater concentrations** (Figure 7-3). For a given sampling event, concentrations can be displayed by plotting symbols of a certain size or color at the sample location. Contour maps also can be constructed. Like those described above, these plots also use colors or lines to indicate the concentrations at different locations. However, with contour plots, concentrations are mapped for the entire area by extrapolating data to areas that have no monitoring points.

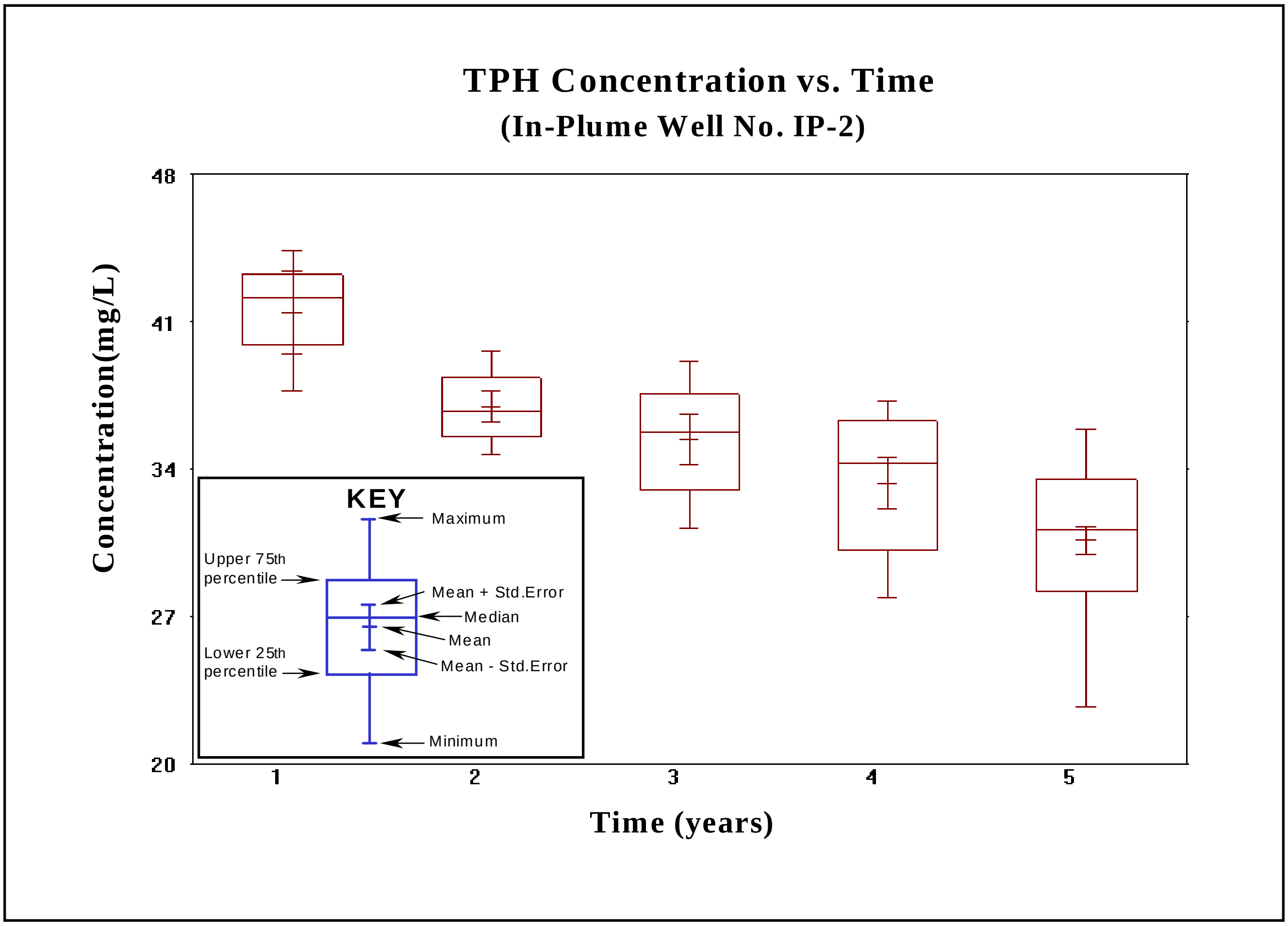


Figure 7-1. Example Box Plot

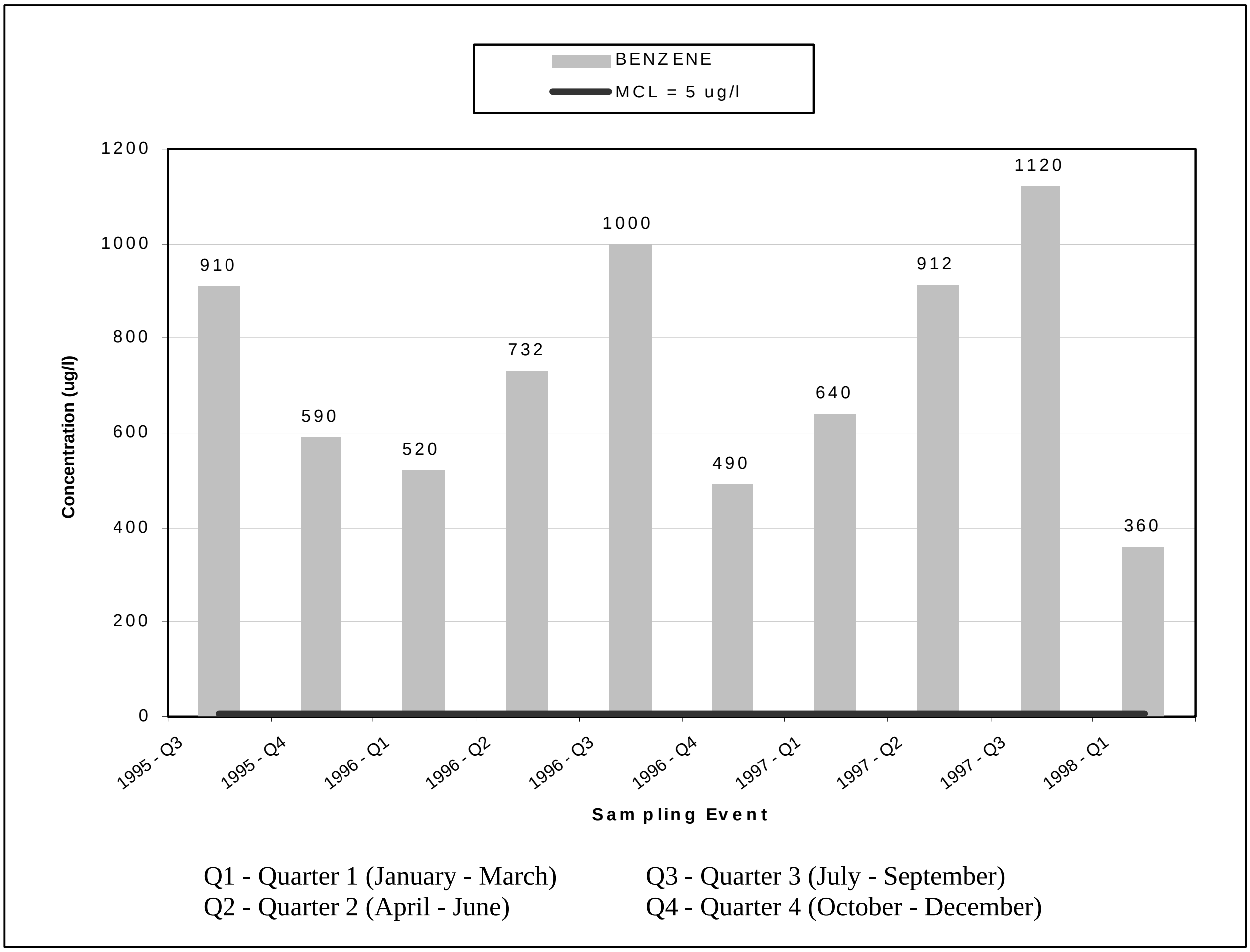


Figure 7-2. Example Time Trend Graph Showing Potential Seasonal Fluctuation

7.1.3 Tabular Data Formats

Tabular formats can be used to support conclusions from more in-depth data evaluations. Although more rigorous data evaluations are often required to objectively evaluate the data and to support decisions, tabular displays provide a convenient method for presenting quantitative information.

Tabular displays can present an informative summary of statistics and of results from statistical tests. Shading may be used to emphasize values above some criteria. Table 7-1 is an example of the type of information that can be provided in a tabular format. Tables summarizing concentration levels observed over a period of time can be constructed for a given monitoring well. Tables can also provide details of the statistical means comparisons by displaying summary statistics necessary for the comparisons.

Table 7-1. Example Table of Summary Statistics
Monitoring Well #1 Data from Last 8 Monitoring Events

Compound	Number Detected Results/Total Samples	Range of Detected Values		Mean	Standard Deviation	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Upgradient UTL	Baseline UTL	Regulatory Standard (i.e., RBC)
		Minimum	Maximum							
Metals (mg/L)										
Chemical A	8/8	0.794	***37.6***	6.30	6.75	0.656	11.9	4.23	7.31	21.0
Pesticides/PCBs (µg/L)										
Chemical B	7/8	0.842	***9.86***	3.43	1.90	1.84	5.02	5.48	6.46	0.810
Chemical C	8/8	0.211	***8.02***	2.70	2.86	0.309	5.25	7.52	5.80	0.140
Chemical D	5/8	0.0927	***1.86***	0.382	0.380	0.0643	0.700	0.568	0.398	0.0210
Semivolatiles (µg/L)										
Chemical E	6/8	0.234	***2.68***	1.34	1.30	0.253	2.43	0.683	0.919	0.810
Chemical F	2/8	0.834	**10.5**	2.65	1.86	0.305	4.21	3.37	11.2	0.140
Volatiles (µg/L)										
Chemical G	1/8	0.0516	0.0516	0.752	0.868	0.0262	1.48	0.0792	0.219	1.40

Shaded values are greater than regulatory standard.
Bolded values are greater than upgradient upper tolerance limit (UTL).
Italicized values are greater than baseline UTL.
Mean, standard deviation, and confidence limits are estimated using proxies and detected results.

7.1.4 Geographic Information Systems (GIS)

A GIS package can help display data spatially and can also be used to construct and track plume or other types of concentration-over-area maps. Standard GIS functions include the ability to pan, zoom in, zoom out, and other standard navigation tools. All of these features can be used to give an effective presentation with the ability to provide real-time responses to any data requests the audience may have. Presentations to regulators and the community can be greatly enhanced by using such a system. Regulator agreement may be obtained during a data visualization meeting, rather than awaiting comments on bulky documents. These applications can be linked directly to a database to further streamline data handling and reduce errors associated with redundancy between multiple sources of data storage. This in turn could be accessible to all environmental personnel via a central server and ideally the installation Intranet.

GIS also provides a powerful tool for interpreting site data. Since different "layers" of information can easily be toggled on and off, users can look separately at any number of analytical parameters, site physical features, and hydrogeological data. Figure 7-3 shows an example of a GIS-generated figure that includes comprehensive site data. Alternatively, it is just as easy, and in some cases very useful, to view different combinations of these parameters simultaneously. By generating sequential realizations of monitoring you can effectively estimate mass of contaminant, monitor plume movement, plume size, and changes in contaminant migration directions. Section 9.3 discusses the applicability of GIS presentation and data evaluation tools to monitoring programs in more detail.

GIS applications have many uses in optimizing monitoring programs, particularly for comparing monitoring data to your decision criteria. The ability to continuously track a plume's size and shape allows for decision-making in regard to which wells to sample and when to shut down active remediation systems. For instance, consider the following:

- If a plume is determined to be shrinking, wells once within the plume may become downgradient wells. Wells further downgradient may be eliminated from monitoring.
- If changes to plume size and contaminant concentrations become insignificant over time, consideration may be given to shutting down active remediation and allowing natural attenuation to take place.
- If a plume appears to be growing, additional wells may need to be identified or installed to track the plume edge. In addition, changes may be needed to the remediation system to prevent off-site migration of contaminants.

Additional uses of this type of system involve tracking of individual monitoring points over time. By querying several rounds of data for a single monitoring point, either in tabular or graphic format, decisions can be made regarding that monitoring point. If the decision criteria have been established, GIS tools/applications make it easy to make decisions based on the data. For example:

- If contaminant concentrations appear to be decreasing, the well may be eliminated from the program, depending on its location, or monitored less frequently.
- If contaminant concentrations have leveled off, the well may be proposed for less frequent monitoring.
- If contaminant concentrations appear to be increasing, the well should be kept in the groundwater monitoring program and monitored at the current frequency.

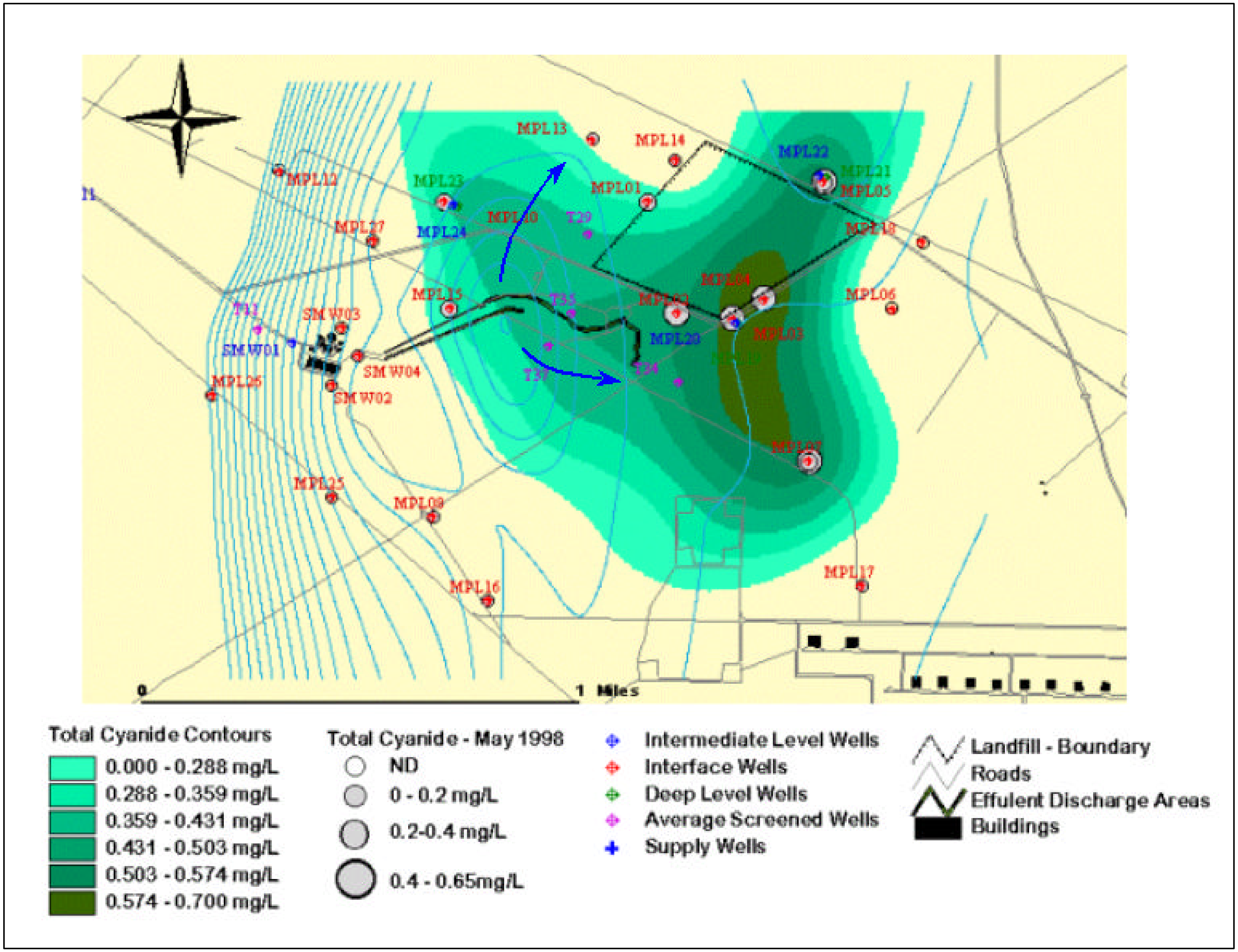


Figure 7-3. GIS-Generated Contaminant Concentration Contour Map

7.1.5 Custom Database Tools

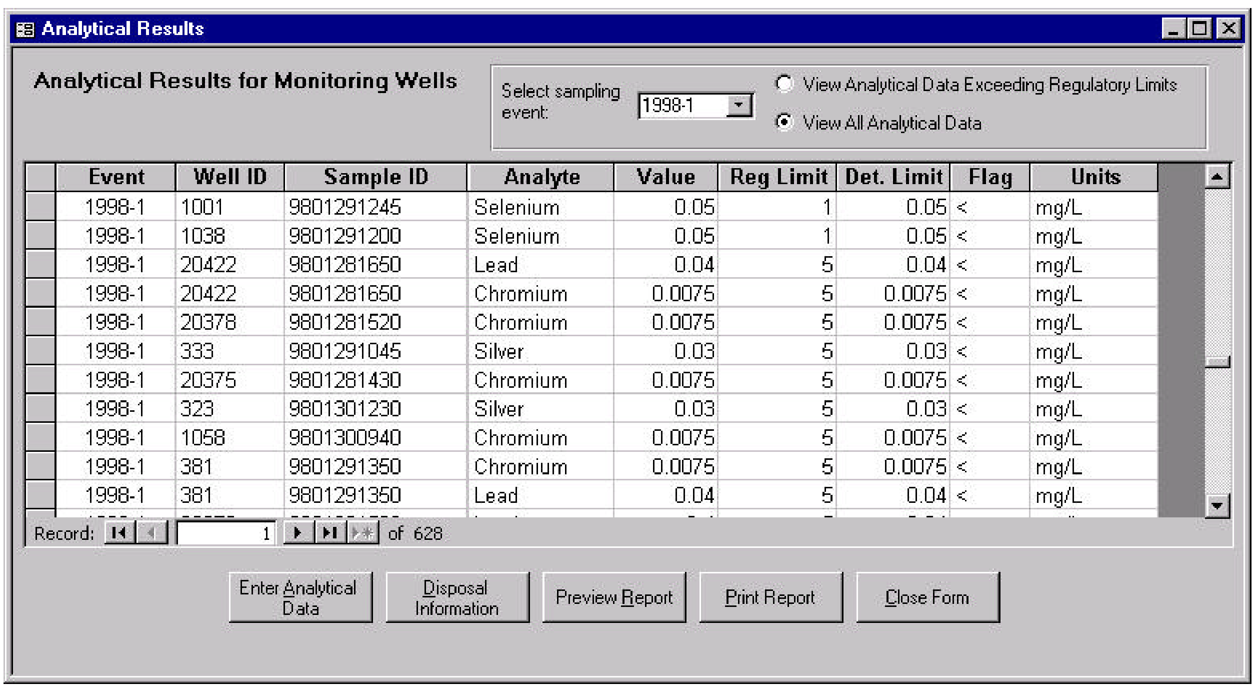
The management of large amounts of data can be done most effectively in electronic format. Customization of off-the-shelf database software, such as Microsoft® Access, will allow you to store, manipulate, and report data according to your needs. Managing your data electronically will facilitate the use of virtually all of the data evaluation tools described in this section. In addition, retrieving the data you need to compare with your decision criteria is much faster and easier than rifling through the last four quarterly reports. By querying several rounds of analytical data for an entire site, decisions regarding program optimization may be made. The types of decision criteria that may be supported by custom database queries include:

- If an analyte has not been detected in four sampling rounds, it should be eliminated from the analyte list for that site; and
- If no analytes of concern have been detected at concentrations above action levels for three or more rounds, discontinue monitoring at the site.

Figure 7-4 shows an example of a custom database application geared toward quickly retrieving all data for a given sampling round, or only data that exceed some standard.

In conjunction with the querying capabilities of a custom database, automatic report table generation can also streamline the reporting process. Data tables can be generated literally in minutes by creating a report format that is fed by an updated query after every sampling round. Figure 7-5 shows an example of a report table that is automatically generated by a custom database.

Example: *NWIRP Dallas has implemented a custom database to electronically manage their IRP data. This tool facilitates tracking of contaminant concentrations and groundwater gradients and flow direction. NWIRP Dallas has also analyzed groundwater monitoring data from sampling events, performed trend analysis, and contoured the data in order to recommend program improvements.*



Event	Well ID	Sample ID	Analyte	Value	Reg Limit	Det. Limit	Flag	Units
1998-1	1001	9801291245	Selenium	0.05	1	0.05	<	mg/L
1998-1	1038	9801291200	Selenium	0.05	1	0.05	<	mg/L
1998-1	20422	9801281650	Lead	0.04	5	0.04	<	mg/L
1998-1	20422	9801281650	Chromium	0.0075	5	0.0075	<	mg/L
1998-1	20378	9801281520	Chromium	0.0075	5	0.0075	<	mg/L
1998-1	333	9801291045	Silver	0.03	5	0.03	<	mg/L
1998-1	20375	9801281430	Chromium	0.0075	5	0.0075	<	mg/L
1998-1	323	9801301230	Silver	0.03	5	0.03	<	mg/L
1998-1	1058	9801300940	Chromium	0.0075	5	0.0075	<	mg/L
1998-1	381	9801291350	Chromium	0.0075	5	0.0075	<	mg/L
1998-1	381	9801291350	Lead	0.04	5	0.04	<	mg/L

Figure 7-4. Custom Database Query

1998 Event 1 Analytical Data

Sample ID	Analyte	Value	Det. Limit	Reg. Limit	Units
Well ID	**1000**				
9801301245	Arsenic	< 0.061	0.061	5	mg/L
9801301245	Barium	0.353	0.001	100	mg/L
9801301245	Cadmium	0.347	0.008	1	mg/L
9801301245	Chromium	0.098	0.0075	5	mg/L
9801301245	Copper	2.74	0.007		mg/L
9801301245	Lead	0.376	0.04	5	mg/L
9801301245	Mercury	< 0.0003	0.0003	0.2	mg/L
9801301245	molybderum	< 0.0086	0.0086		mg/L
9801301245	Nickel	< 0.016	0.016		mg/L
9801301245	pH	7.34	0.05		pH units
9801301245	Selenium	< 0.05	0.05	1	mg/L
9801301245	Silver	< 0.03	0.03	5	mg/L
9801301245	TOX	0.44	0.2		mg/L
9801301245	TPH	7800	0.5	500	mg/L
9801301245	Zinc	0.775	0.005		mg/L
Well ID	**1001**				
9801291245	Arsenic	< 0.061	0.061	5	mg/L
9801291245	Barium	0.022	0.001	100	mg/L
9801291245	Cadmium	< 0.008	0.008	1	mg/L
9801291245	Chromium	< 0.0075	0.0075	5	mg/L
9801291245	Copper	< 0.007	0.007		mg/L
9801291245	Lead	0.059	0.04	5	mg/L
9801291245	Mercury	< 0.0003	0.0003	0.2	mg/L
9801291245	molybderum	< 0.0086	0.0086		mg/L
9801291245	Nickel	< 0.016	0.016		mg/L
9801291245	pH	7.3	0.05		pH units
9801291245	Selenium	< 0.05	0.05	1	mg/L
9801291245	Silver	< 0.03	0.03	5	mg/L

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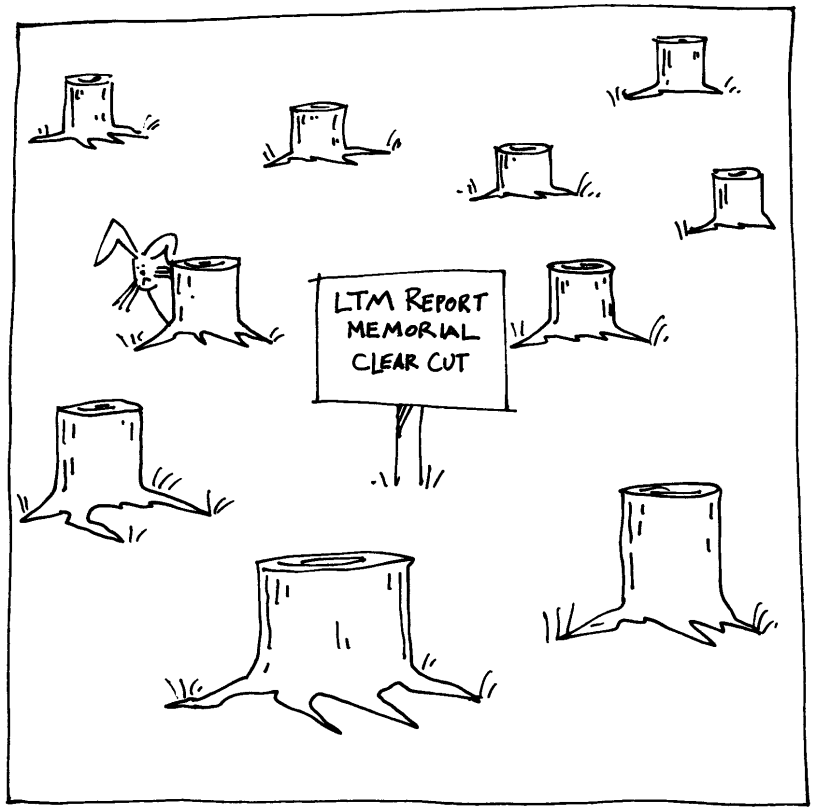
Figure 7-5. Custom Database Automatic Report

7.2 Report Streamlining



Report streamlining is another method to significantly cut monitoring costs, especially in a program with quarterly monitoring requirements. An increasingly common approach is to have the groundwater monitoring contractor submit a ring binder each year. This "living" document is tabbed to provide space for quarterly and semiannual monitoring results once the data are available. Then, on a yearly basis, a more formal annual monitoring report is submitted and inserted in the front of the document. Although the annual reports are submitted in draft and final versions, quarterly or semiannual reports may be submitted only once or the draft may be submitted electronically.

This approach allows for several other efficiency improvements. First of all, all general "cut and paste" information in the quarterly reports can be eliminated, minimizing the amount of text that must be produced. If only data are submitted, it is unlikely that there will be any comments, thus eliminating the need for a draft. If changes are necessary due to a data reporting error, replacement pages may be submitted. Raw data, purging logs, and so forth, should be submitted as an appendix, either on a quarterly or annual basis.

Other information, such as sample chain-of-custody forms, should be kept in project folders for reference as necessary. Copying these forms into an appendix of each report takes up space and is of little use to the average report reader.

Focusing on tabular and graphic presentation styles helps to reduce review time. Presenting a summary table of the data, using shading or some other method for highlighting detections that exceed some standard, increases the readability of the information.

Example: *MCB Camp Lejeune has implemented a streamlined reporting process. Semiannual reports are inserted into a binder assigned to each Operable Unit (OU) as they are produced. Generally, only one draft of each report is issued. MCB Camp Lejeune is also handling IRP data electronically and has written specifications for contractors to follow when providing data in electronic format.*

8.0 How Can I Ensure Regulatory Acceptance?

8.1 Teaming with Regulators for Monitoring Program Design

At various phases of the IRP, you are required by law to gain regulatory agency acceptance and approval. Much of the data and justification that you may use to gain this approval will come directly from your monitoring program. Examples include such IRP phases as Response Complete (RC) and Site Closeout. Obviously, you run a great risk if the agencies have not reviewed and approved your monitoring program prior to this point. A worst-case scenario is that the agencies reject your data and analysis; and require you to redo much of your past efforts, often at significant time and cost. This is not where Navy RPMs want to end up; thus, regulatory agency agreement for your program is critical.

Achieving and maintaining regulatory agency approval and agreement for your groundwater monitoring program is an ongoing process; and ideally, it should start with your program design activities. In fact, one of the most efficient ways to make your state, local, and federal regulatory agencies part of the monitoring program team is to involve them in the planning, design, review, and approval of your GMP.

Example: *MCB Camp Lejeune has a detailed work plan for their entire groundwater monitoring program. In addition, MCB Camp Lejeune has an excellent "team approach" with the regulators. They hold bimonthly meetings with the regulators to review monitoring data for each OU and make consensus recommendations for changes and improvements.*

The GMP is your most important tool for documenting decision criteria and procedures necessary to optimize your monitoring program. It is a document incorporating elements from all of the chapters contained in this guidance manual. As previously discussed, these include the goals and objectives of the monitoring program, the CSM, DQOs, regulatory decision framework, monitoring points, sampling and analytical methods, reporting procedures and formats, program review procedures and frequencies, and criteria for program optimization and site closeout. *The GMP is the foundation for ensuring continuity and consistency in your program. It is the written documentation and justification of your program goals, objectives, decision criteria, and procedures in case of personnel turnover either for your installation, contractors, or regulatory agencies.*

Although a regulator's perspective of the content requirements for a GMP may differ from yours, a GMP that considers only regulatory agency requirements will usually be incomplete and insufficient from the Navy RPM point of view. Typically, regulatory agencies will want to confirm that you've adequately addressed the following points:

- Will the goals and objectives in the GMP satisfy the requirements in applicable installation decision documents, e.g., RODs, Statement of Basis, and/or permits?
- Does the monitoring network in the GMP provide adequate coverage for the contaminated plume?
- Are the GMP procedures consistent with local, state, and federal regulations?
- Are the analytical methods and QA/QC procedures consistent with DQOs?

Navy RPMs, however, should also consider other requirements in which the agencies may not be interested. In particular, pay close attention to performance monitoring requirements for active and passive remedial actions. One specific example is the collection of data to verify the occurrence and rate of MNA at your site. This information is almost always useful to the RPM, but the regulatory agencies may not be as interested.

Once the GMP has been written and approved by your entire team, the process shifts toward maintaining regulatory agency acceptance during the program implementation phase, often lasting many years. The main points to remember in this process are proactive communication, reporting, and periodic program evaluations and review. At a minimum, you should consider the following practices:

- Establish a standard data reporting format and frequency with agency input and approval at the beginning of your program.
- Require your contractor(s) to evaluate the entire program on at least an annual basis and provide recommendations for program optimization and improvement. In particular, the contractor should clearly compare the trends and results of the monitoring program against the decision criteria and framework specified in your GMP.
- Agree to meet with the agencies on at least an annual basis to review and/or approve the monitoring program results and recommendations for optimization and update the GMP as necessary. In addition, a 5-year review period should be used as a tool to make major decisions regarding remedy effectiveness and appropriateness, ceasing remedial actions, or closing out sites.

8.2 Teaming with Regulators for Monitoring Program Optimization

The degree of regulatory agency acceptance and buy-in for an existing monitoring program usually falls into one of several categories:

Case No. 1: A true team environment exists encouraging and promoting active modification and optimization to achieve monitoring program goals in a cost-effective manner, while protecting human health and the environment.

Case No. 2: The program already has regulatory acceptance and approval, but no effort has been made to modify or change the program and the current approach is onerous and expensive due to overly stringent requirements.

Case No. 3: The program is being conducted with little or no regulatory interaction, acceptance, or approval.

Obviously, Case No. 1 is the ideal for which you should strive. However, even in this instance, you should verify that the program has a written and approved GMP in place. Many an empowered and synergized program team has come to a grinding halt after a sudden change in key installation or regulatory agency personnel. If the goals, objectives, and procedures of the monitoring program have not been documented in a well-written, approved GMP, the program runs the risk of losing focus and purpose, and wasting valuable resources in needless rework.

Often, Case No. 2 can be the most difficult situation for pursuing regulatory acceptance of program optimization initiatives. Typically, these are monitoring programs with significant “history” associated with them, a GMP (or similar document) already approved, aggressive regulatory agency personnel, and/or a “business as usual” mindset by the existing team. In these instances, an objective assessment of the relative strengths and weaknesses of the monitoring program can be difficult to achieve due to the inherent biases of your existing project team, especially if the program has been ongoing for several years. In this situation, it is often advantageous to hire an independent contractor to assess and provide optimization recommendations for your program. This approach ensures a fresh perspective and an objective evaluation and assessment. With the independent contractor’s recommendations as a basis, you and your entire team (contractor and regulatory agency personnel) can then meet to reevaluate the GMP, along with current program results and trends. Then discussion and subsequent agreement on proposed modifications and optimization initiatives can be facilitated.

Case No. 3 should be remedied at the earliest opportunity, because it presents the most risk to the Navy in terms of cost and monitoring program rework. Years of data collection and evaluation could be wasted if the regulatory agencies have not reviewed and approved your monitoring program goals, objectives, and technical approach. However, the opportunity still exists to bring the regulatory agencies into the program through the GMP planning and review process previously discussed. As a starting point in the process, the RPM can schedule a comprehensive monitoring program review meeting with the agencies. The primary purpose would be to "educate" the agency personnel by reviewing the current GMP (if available) and associated monitoring program procedures and results. This meeting and subsequent discussion can act as the foundation for a new or revised GMP and program with full agency review and approval. Even if the review of the GMP results in higher monitoring costs, a net cost avoidance may be realized if you achieve regulator approval and avoid the need to repeat monitoring activities.

9.0 What Tools Can I Use to Facilitate Optimization of My Monitoring Program?

9.1 Statistical Tools

This section describes statistical tools that can be used to achieve some typical groundwater monitoring program objectives. This section is organized by objective and presents the statistical methods most appropriate for answering each objective. Appendix C discusses statistical methods in greater detail.

9.1.1 Identify Concentrations that Exceed Regulatory Limits

Groundwater monitoring programs are generally designed to determine when groundwater concentrations of certain constituents are above regulatory limits (such as risk-based concentrations, state or federal standards, maximum concentration limits, water quality criteria, etc.). There are several methods for comparing concentrations to these levels, depending on the project objectives.

Direct Comparison—In general, it is usually adequate to compare each detected result to the regulatory limit. This method is simple and, with minimal effort, summaries can be produced showing how many detected results exceed the criteria. However, this technique is unforgiving when it comes to infrequent, anomalous, high values. If a few anomalously high concentrations are resulting in continued monitoring at a site, it is worthwhile to conduct a more in-depth data evaluation using one of the following methods, or those described in Section 9.1.2.

Upper Tolerance Limit—If the objective is to identify chemicals that have some percentile of concentrations that exceed the regulatory limit, then an upper tolerance limit (UTL) is calculated. If the UTL does not exceed the regulatory limit, then there is a high level of certainty that the specified percentile of the groundwater data do not exceed the regulatory limit.

Means Comparison—If the objective is to identify chemicals that have concentrations typically (on average) greater than the regulatory limit, then a one-sample means comparison should be used. A one-sample means comparison determines if concentrations are, on average, greater than regulatory criteria.

9.1.2 Identify Outliers or Extreme Concentrations

Statistical methods that identify outliers are useful for classifying results that are extremely small or large compared to the rest of the data. Statistical outliers can be identified using a box plot or an outlier test.

Box Plots—Box plots are useful graphical tools for displaying extreme concentrations as well as the central tendency and variability of the data. Using a box plot, investigators can identify more than one result as an outlier. Outliers can be present at both ends of the concentration range (refer to Figure 7-1).

Outlier Test—An outlier test is provided by the EPA *(Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities*, April 1989, and *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities: Addendum to Interim Final Guidance*, June 1992). Unlike box plots, this test is limited to identifying one point, either maximum or minimum, as an outlier.

The purpose of identifying outliers is to ensure that anomalous values are not erroneous and do not unduly influence data interpretation. Once an outlier has been identified, the project team should review the data to determine if there is a reason why the outlier should be disregarded. In general, outliers should not be excluded from data evaluation without a specific reason, such as evidence of contamination, laboratory error, or transcription error. If a plausible reason can not be found for removing a statistical outlier, the result should be treated as a true but extreme value. Although the value should not be excluded from the data set, additional evaluation may be conducted so that they do not unduly influence statistical calculations, such as the mean. This may involve computing two different sets of summary statistics, both with and without the outlier.

9.1.3 Identify Differences in Concentrations Between Two Populations

Generally when two sets of data are compared, several statistical comparisons can be performed. These include two-sample means comparisons, individual comparisons, and quantile tests. Each of these comparisons is useful and provides different information about the data. Two-sample means comparisons provide an overall picture of the differences between downgradient and upgradient data ranges. Individual comparisons provide information about "hot spots" for specific well locations and chemicals. Quantile tests view downgradient results as a whole, rather than as individual results. Only the means comparisons and individual comparisons, though, provide a systematic way of quantifying decision uncertainty.

Two-Sample Means Comparison—If the objective of the program is to identify any chemical with an average downgradient concentration that exceeds the average upgradient concentration, then a two-sample means comparison is appropriate. Two-sample means comparisons determine if downgradient concentrations are, on average, greater than upgradient concentrations.

Individual Comparison and Quantile Test—If the objective of the program is to identify cases when *any* downgradient concentrations differ from concentrations seen in upgradient wells, then an individual comparison or a quantile test is more appropriate.

9.1.4 Identify Differences in Chemical Concentrations

When more than two sets of data are compared, the appropriate statistical method to use is an ANOVA, in conjunction with multiple comparison tests or contrast tests. An ANOVA is similar to a two-sample means comparison (as described in Section 9.1.3) except that averages for several different groups can be evaluated simultaneously. An ANOVA may be useful in instances where it is suspected that concentrations or trends in concentration of one or more contaminants are related in some way, for example as in the degradation of TCE and the production of daughter products such as cis-1,2 dichloroethene. Another example use of ANOVA would include a statistical comparison to determine the significance of spatial variability at a site. By performing an ANOVA on data from upgradient or background wells, a determination on the significance of spatial variability at the site can be ascertained. This data could be helpful in explaining variability in data collected from wells affected by contamination, helping delineate plume boundaries, movement, and total mass. Statistical verification of such trends can have important implications for remedial design and operation as well as regulatory approvals.

9.1.5 Test for a Trend

Typically, spatial and temporal trend analyses start by visually inspecting plots of analytical results for a well or group of wells over time or as a function of distance from the source. Visual examination of such data is a highly sensitive means of detecting trends or potential trends in the data. If these plots do not yield obvious trends, a more in-depth statistical analysis may be useful. To identify trends using statistics, either the Mann-Kendall test or regression analysis may be used. The Mann-Kendall test should, generally, be applied as the first step in assessing trends. Regression analysis may be appropriate for assigning numerical values to trends identified as significant, as in calculating natural attenuation rates, contaminant mass removal, or rates of plume advance or retreat.

9.1.6 Evaluate Data Spatially

Spatial statistical methods, or geostatistics, can be applied to groundwater monitoring data to help define plume(s) and provide a basis for ceasing to monitor a well and/or a chemical.

Semivariograms—Semivariograms can help define plume(s) by quantifying relationships between samples taken at different well locations. Separating wells into various regions or plumes can decrease the variability of concentrations and can allow for more accurate statistical tests and decision making. This method may also provide information for effective remedial design by distinguishing areas that require remediation from those that do not.

Kriging—Kriging maps can be used to delineate areas of contamination and to develop decisions about further sampling by providing a powerful visual argument that the current delineation is either adequate or not. This type of information can be extremely useful in discussions with regulators. Uncertainty maps (maps of uncertainties associated with kriging predictions) can indicate whether additional sampling is useful. Also, if estimated chemical concentrations are substantially lower than comparison values (regulatory limits, upgradient UTLs, etc.), even after accounting for uncertainty, then it may not be necessary to collect additional samples, even when sampling is sparse across that area or well.

9.2 Groundwater Modeling

Groundwater modeling, in its different forms, can provide valuable information for management of monitoring programs, including determination of flow velocities, contaminant transport velocities, plume center-of-mass (COM) movement, and plume spreading or plume degradation. Groundwater contaminant modeling can range in complexity from simple "back-of-the-envelope" analytical calculations, to semi-analytical techniques, to multi-phase stochastic numerical models that account for heterogeneous geology, hydrodynamic dispersion, contaminant mass loss functions, and thermodynamic chemical equilibria. This section discusses some common applications for groundwater modeling relevant to monitoring programs, along with a brief discussion of general modeling limitations.

9.2.1 Flow Velocity Modeling

Flow velocity, or transport-time modeling can provide order-of-magnitude estimates of groundwater flow velocity. In general, you must have an estimate of the groundwater gradient, media hydraulic conductivity, and media porosity for the site to make a flow velocity estimate. This information is valuable in determining sampling frequencies for a monitoring program. When estimating flow velocities, you should be aware that the velocity of groundwater movement is not always equal to the velocity of dissolved constituents. Due to physical absorption onto the soil and other factors such as chemical transformation and biological degradation, a plume of contamination may move slower than the groundwater in which it is dissolved. *Plumes of different contaminants at the same site may also move at different velocities, or a plume may separate over time into different constituents, as some contaminant compounds may adsorb or degrade faster than others may.*

9.2.2 Contaminant Plume Modeling

Advanced methods of groundwater modeling can be employed to provide better understanding and prediction capability of contaminant movement. There are many commercial groundwater fate and transport models available for the system designer. Depending upon the capabilities of a particular model, modeling input needs and processing time will vary. Under good calibration, computer flow models can provide accurate, three-dimensional realizations of groundwater and contaminant plume movement. For example, you may be able to visualize and evaluate the consequences of different pumping schemes in a pump and treat system, and evaluate plume diversion or capture. In evaluating the placement of monitoring wells, an accurate, calibrated model could provide insight into where contamination would most likely leave a site, or how potential off-site hydraulic influences like a pumping well might change future groundwater gradients at a site. Lateral spreading of a plume by hydrodynamic dispersion could also be approximated by fate and transport models. This could have implications in determining the number and location of corrective action observation wells and/or POC wells.

9.2.3 Groundwater Modeling Limitations

Not all sites are well suited for fate and transport modeling of groundwater contaminants. Aquifers that are geologically homogenous, are not comprised of different perched units, and are well characterized lend themselves to accurate fate and transport modeling. In general, as geologic complexity of a site increases, the cost of modeling increases while the modeling accuracy decreases. Sites that are geologically highly variable either horizontally or vertically are, for practical purposes, not good candidates for using deterministic groundwater models. The accuracy of groundwater flow models depends on the hydraulic conductivity parameter. While there are numerous ways to characterize hydraulic conductivity, each has its own limitations. You need to carefully scrutinize how the physical parameters going into the model were identified and qualify all modeling findings accordingly. The extension of flow models into chemical fate and transport models introduces more assumptions and physical/chemical parameters that must be characterized. Again, the overall accuracy of the model will depend directly on the quality of the data used for the input parameters.

9.3 Geographic Information Systems

Data Evaluation—GIS offers a powerful means for interpreting many types of data associated with a site. In general, GIS offers a broad spectrum of capabilities including visualization, analysis, and querying of electronic data. Most commercially available GIS programs accept the use of common base mapping formats, including CAD drawings, DXF files, and USGS Digital Elevation Maps (DEMs). Overlapping field sampling data with geo-referenced base mapping can provide data analysts, engineers, decision-makers and stakeholders with an accurate, scaled representation of a site's contaminant plume. Since different "layers" of information can easily be toggled on and off, users can look separately at any number of analytical parameters, site physical features, and hydrogeological data. Alternatively, it is just as easy, and in some cases very useful, to view different combinations of the aforementioned parameters at the same time. Querying capabilities and inter-program connectivity features offered by GIS packages allow for retrieval and storage of data sorted by any number of parameters including date, location, analyte, and depth-to-sample.

Figure 7-3 illustrates an example output figure using ESRI ArcView ® Version 3.1 GIS software. This single illustration includes surface physical features, well locations, potentiometric surface mapping, directional groundwater-flow vectors, contaminant "bubble" plots, and a contaminant plume iso-concentration map modeled from contaminant data for a single sampling event from a categorized depth of wells. If a GIS application is incorporated into a groundwater monitoring program, real-time maps can be generated as soon as analytical lab data are received. By generating sequential realizations of monitoring data as illustrated in Figure 7-3, you can effectively estimate mass of contaminant, monitor plume movement, plume size, and changes in contaminant migration directions. Transposing these graphical data with "real world" base mapping allows for continued review and identification of suspected source areas and contaminant hotspots as well as easy identification of downgradient receptor locations that may be impacted in the future.

Depending on the complexity of the site to be modeled, you may consider more sophisticated software packages to aid in analysis and visualization of geological, geohydrological, and contaminant sampling data. A recent class of new visualization software includes true three-dimensional programs capable of generating high quality three-dimensional renderings and animations. Most of these programs provide a suite of geological modeling capabilities and spatial analysis tools. Examples of this type of visualization software include the following products:

- ESRI ArcView® with ESRI 3-D Analyst extension;
- Environmental Visualization System (EVS) from C-Tech;
- EVS for ArcView from C-Tech; and
- Visual Groundwater from Scientific Software Group.

Incorporation of GIS and three-dimensional visualization software can be either planned and started with a new groundwater monitoring program, or brought online at any time for an existing groundwater monitoring program. Judgment should be used when deciding what historical data should be included in the GIS. Availability of data in electronic format is an important factor when deciding what data to use, as manual data entry is time consuming and requires a high degree of quality control. A minimal amount of base mapping will be necessary to fully realize the power of GIS programs. At a minimum, you would want to include coverages of monitoring well positions, important facilities, remediation systems, supply wells, property boundaries, and relevant off-site features. The use of field global positioning system (GPS) receivers allows for inexpensive horizontal surveying with sub-meter accuracy.

Real Time Presentations—Figure 9-1 shows a screen shot of a GIS application that allows the user to generate plume maps using data from a monitoring program. By selecting a site, a contaminant of concern, and a sampling round, a custom query is generated. The concentration data from the query are subsequently contoured and displayed on the screen. A table containing the query data is also displayed.

By clicking on a well, building, source area, or other feature in the GIS display, you can bring up specific data describing the chosen feature. For example, by clicking on a specific well you may bring up well construction, water level, or contaminant concentration data. Clicking on a site or Operable Unit may bring up pertinent information such as contaminants of concern, site activities, and dates of operation.

Standard GIS functions include the ability to pan, zoom in, zoom out, and other standard navigation tools. All of these features can be used to give an effective presentation with the ability to provide real-time responses to any data requests the audience may have.

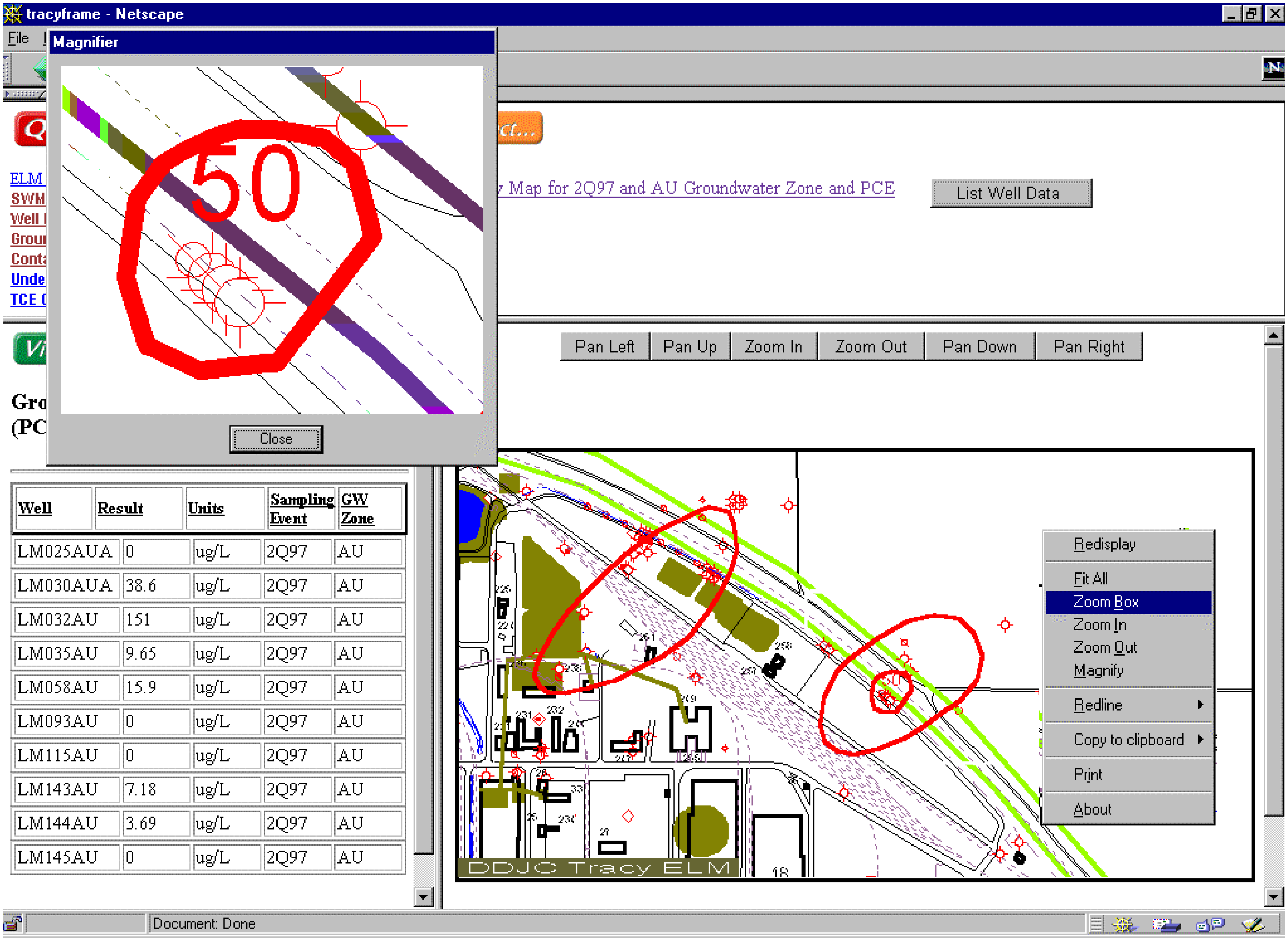


Figure 9-1. Example Real-Time GIS Map

9.4 Contracting Strategies

9.4.1 Suggested Expertise for Optimization or Design Team

Appropriate design and optimization of groundwater monitoring programs is a logical and straightforward process, but it does require the expertise of an experienced, multi-disciplinary team. In general, the make-up and experience levels of the contractor's project team is determined by the size, complexity, and scope of the monitoring program to be designed or optimized. Potential contractors should, at a minimum, have access to individuals with the following experience. In most cases, project personnel can assume more than one of the roles listed below:

- *Project Manager* with demonstrated optimization experience.
- *Mid-level to Senior-level geologist or hydrogeologist* with specific experience in the geologic formations typical at your installation.
- *Project chemist*.
- *Statistician* with specific experience evaluating monitoring data.
- *Toxicologist or risk assessment specialist.*
- *CADD/GIS specialist.*
- *Groundwater modeler.*
- *Mid-level to Senior-level engineers* with monitored natural attenuation (MNA) and active groundwater remediation (e.g., pump and treat) experience.
- *RCRA and CERCLA regulatory analysis specialist* with experience specific to your State and EPA Region.
- *Life cycle cost engineer/specialist* to evaluate cost savings, avoidance, and payback periods for appropriate recommendations and alternatives.

All of the roles listed above may not be required for every groundwater monitoring design or optimization project. However, for a typical program with some decision documents (e.g. RODs) and associated active or passive groundwater treatment systems already in place, the above listed skill sets should comprise the minimum requirements.

In addition, for optimization of existing programs, it may be advantageous to hire an independent third party to assess and provide optimization recommendations. This approach ensures a fresh perspective and an objective assessment of the relative strengths and weaknesses of the monitoring program. Often, this can be difficult to achieve with the inherent biases of your existing project team, especially if the program has been ongoing for several years.

9.4.2 Example Statement of Work (SOW) for Optimizing Groundwater Monitoring

General Requirements:

The contractor will employ a multi-disciplinary team and approach to assess and evaluate the adequacy of the groundwater monitoring program strategy and progress at (***insert appropriate installation, OUs and/or sites***). This evaluation will be done in accordance with the DON *Guide to Optimal Groundwater Monitoring*, and other applicable site-specific guidance documents and regulations. The primary purposes of the optimization assessment are to: 1) evaluate whether the current groundwater monitoring program provides the necessary data to verify adequate progress toward site close-out; and 2) provide program optimization recommendations to increase the effectiveness of the program while reducing the overall cost. Both of these purposes must be accomplished without loss of data and information quality.

In accomplishing this evaluation, it is anticipated that the contractor will require the following experience and expertise (edit list as appropriate). Individual project tasks are detailed in subsequent paragraphs.

- *Project Manager* with demonstrated optimization experience.
- *Mid-level to senior-level geologist or hydrogeologist* with specific experience in the geologic formations at (***insert installation/region***).
- *Project chemist*.
- *Statistician* with specific experience evaluating monitoring data.
- *Toxicologist or risk assessment specialist.*
- *CADD/GIS specialist.*
- *Groundwater modeler.*
- *Mid-level to senior-level engineer(s)* with passive (e.g., MNA) and active (e.g., pump and treat) groundwater remediation experience.
- *Regulatory analysis specialist* with experience specific to (***insert State and EPA Region***) and (***insert governing program [e.g., RCRA or CERCLA]***).
- *Life cycle cost engineer/specialist* to evaluate cost savings, avoidance, and payback periods for appropriate recommendations and alternatives.

Task 1: Project Work Plan

Contractor will provide a work plan in draft and final versions. At a minimum, the work plan will include:

- Project description and objectives;
- Project organization including roles, responsibilities, and contact information for team members;
- Description and procedures for primary technical tasks;
- List of project deliverables; and
- Schedule of primary project milestones.

Task 2: Site Visit and Data Gathering

The contractor will perform a site visit to collect the necessary data and interview appropriate personnel to perform a comprehensive evaluation and assessment of the groundwater monitoring program at (***insert installation***). In order to assist installation personnel in preparing for the site visit, a letter request for site-specific data, along with a data needs checklist, will be submitted 3-4 weeks prior to the visit.

In addition, a pre-visit conference call will be conducted to review project goals and objectives, and coordinate on-site logistics and data gathering needs. The call will include the contractor project team, the responsible RPM from the supporting EFD or EFA, and representatives from (***insert installation***). During the site visit, a formal project in-brief and out-brief will be required.

Task 3: Groundwater Monitoring Program Assessment Report

The contractor will produce a report detailing the overall approach, findings, conclusions, and optimization recommendations for (***insert installation***). The report will be delivered in working draft, draft, and final versions, and at a minimum will include an assessment of the elements listed below. In addition, all recommendations will have a suggested priority for implementation; and as appropriate, lifecycle cost savings and/or avoidance will be calculated and presented.

- Overview and Goals of the Monitoring Program, including site closeout and exit strategies.

- Background and discussion of remedial progress to date.
- Adequacy of the CSM.
- Location and number of monitoring points (background, cross-gradient, in-plume, remedial system performance, sentinel, and point-of-compliance monitoring wells).
- Frequency and duration of monitoring.
- Analytes and analytical methods.
- QA/QC requirements.
- Routine frequency and approach for data evaluation, trend analysis, presentation, and reporting.
- Best technical and management practices already in place at the installation.

Task 4: Presentation of Assessment Report Conclusions and Recommendations

The contractor shall prepare for and attend a meeting to present the conclusions and recommendations contained within the report to applicable installation and regulatory agency personnel. A draft version of the presentation will be reviewed and approved by installation personnel prior to the formal presentation to the regulatory agencies.

9.4.3 Example Statement of Work (SOW) for Designing Groundwater Monitoring Program

General Requirements:

The contractor will employ a multi-disciplinary team and approach to design an optimal groundwater monitoring program at (***insert appropriate installation, OUs and/or sites***). This design will be done in accordance with the DON *Guide to Optimal Groundwater Monitoring* and other applicable site-specific guidance documents and regulations. The primary purpose of this design is to describe the detailed decision-making framework, associated procedures, and monitoring network necessary to ensure adequate remedial progress and achievement of site closeout for optimal lifecycle costs at (***insert installation name***).

In accomplishing this design, it is anticipated that the contractor will require the following experience and expertise (edit list as appropriate). Individual project tasks are detailed in subsequent paragraphs.

- *Project Manager* with demonstrated optimization experience.
- *Mid-level to senior-level geologist or hydrogeologist* with specific experience in the geologic formations at (***insert installation/region***).
- *Project chemist*.
- *Statistician* with specific experience evaluating monitoring data.
- *Toxicologist or risk assessment specialist.*
- *CADD/GIS specialist.*
- *Groundwater modeler.*
- *Mid-level to senior-level engineer(s)* with passive (e.g., MNA) and active (e.g., pump and treat) groundwater remediation experience.
- *Regulatory analysis specialist* with experience specific to (***insert State and EPA Region***) and (***insert governing program [e.g., RCRA or CERCLA]***).
- *Life cycle cost engineer/specialist* to evaluate cost savings, avoidance, and payback periods for appropriate recommendations and alternatives.

Task 1: Project Work Plan

Contractor will provide a work plan in draft and final versions. At a minimum, the work plan will include:

- Project description and objectives;
- Project organization, including roles, responsibilities, and contact information for team members;
- Description and procedures for primary technical tasks;
- List of project deliverables; and
- Schedule of primary project milestones.

Task 2: Site Visit and Data Gathering

The contractor will perform a site visit to collect the necessary data and interview appropriate personnel to perform a comprehensive design of the groundwater monitoring program at (***insert installation***). In order to assist installation personnel in preparing for the site visit, a letter request for site-specific data, along with a data needs checklist, will be submitted 3-4 weeks prior to the visit.

In addition, a pre-visit conference call will be conducted to review project goals and objectives and coordinate on-site logistics and data gathering needs. The call will include the contractor project team, the responsible RPM from the supporting Engineering Field Division (EFD) or Activity (EFA), and representatives from (***insert installation***). During the site visit, a formal project in-brief and out-brief will be required.

Task 3: Groundwater Monitoring Program Design Report

The contractor will produce a detailed design report for the (***insert installation***) groundwater monitoring program. The report will be delivered in working draft, draft, and final versions, and at a minimum will include a discussion of the elements listed below.

- **Overview, Framework, and Goals of the Monitoring Program:** including a description of the conceptual site model, site history, hydrogeology, regulatory framework, performance monitoring requirements for any active and/or passive treatment systems, and natural attenuation/biodegradation processes.
- **Best Technical and Management Practices:** including regulatory agency approval and buy-in of past monitoring efforts, and examples of innovative technical monitoring and/or data presentation approaches.
- **Location, Types, and Number of Monitoring Points:** including identifying background, upgradient, crossgradient, in-plume, performance monitoring, sentinel, and point-of-compliance wells; ensuring adequacy of coverage; and decision (exit) criteria to reduce the number of wells as the program progresses.
- **Monitoring Frequency and Duration:** including suggested frequencies for different wells; use of groundwater modeling and plume contours to determine contaminant movement rates; and decision criteria for reducing monitoring frequency and duration.
- **Appropriate Analytes and Analytical Methods:** including identifying analytes for initial monitoring; decision criteria to reduce the number of analytes as monitoring progresses; and appropriate QA/QC requirements.
- **Data Collection and Field Procedures:** including a discussion of micropurging and diffusion samplers, as appropriate.

- **Data Evaluation, Presentation, and Reporting:** including a discussion of data visualization techniques, use of Geographic Information Systems (GIS), custom database querying and reporting tools, graphic and tabular presentation formats, and plume maps and contours.

Task 4: Presentation of Groundwater Monitoring Program Design Report

The contractor shall prepare for and attend a meeting to present the approach and recommendations in the design report to the applicable installation and regulatory agency personnel. A draft version of the presentation will be reviewed and approved by installation personnel prior to the formal presentation to regulatory agencies.

10.0 Where Else Can I Go for Help?

10.1 Useful Web Sites

10.1.1 State Environmental Agencies

Alabama	www.adem.state.al.us
Alaska	www.state.ak.us
Arizona	www.adeq.state.az.us
Arkansas	www.adeq.state.ar.us
California	www.state.ca.us
Colorado	www.state.co.us
Connecticut	www.state.ct.us
Delaware	www.dnrec.state.de.us
Florida	www.state.fl.us
Georgia	www.dnr.state.ga.us
Hawaii	www.state.hi.us
Idaho	www.state.id.us
Illinois	www.ipcb.state.il.us
Indiana	www.state.in.us\idem
Iowa	www.state.ia.us
Kansas	www.state.ks.us
Kentucky	www.state.ky.us
Louisiana	www.deq.state.la.us
Maine	www.state.me.us
Maryland	www.mde.state.md.us
Massachusetts	www.state.ma.us
Michigan	www.deq.state.mi.us
Minnesota	www.pca.state.mn.us
Mississippi	www.deq.state.ms.us
Missouri	www.state.mo.us
Montana	www.deq.state.mt.us
Nebraska	www.deq.state.ne.us
Nevada	www.state.nv.us
New Hampshire	www.state.nh.us/des
New Jersey	www.state.nj.us/dep
New Mexico	www.state.nm.us
New York	www.dec.state.ny.us
North Carolina	www.ehnr.state.nc.us
North Dakota	www.ehs.health.state.nd.us
Ohio	www.epa.ohio.gov
Oklahoma	www.deq.state.ok.us
Oregon	www.deq.state.or.us
Pennsylvania	www.dep.state.pa.us
Rhode Island	www.state.ri.us/dem
South Carolina	www.state.sc.us
South Dakota	www.state.sd.us/denr
Tennessee	www.state.tn.us
Texas	www.tnrcc.state.tx.us
Utah	www.deq.state.ut.us
Vermont	www.anr.state.vt.us
Virginia	www.deq.state.va.us
Washington	www.access.wa.gov
West Virginia	www.state.wv.us
Wisconsin	www.leg.state.wi.us/rsb/code
Wyoming	www.state.wy.us

10.1.2 Optimization-Related Websites

Navy

Department of the Navy RAO/LTM Optimization Web Site
http://enviro.nfesc.navy.mil/ps/raoltm/index.html

SWDIV Procedural Guidance for Statistically Analyzing Environmental Background Data
http://www.nfesc.navy.mil/enviro/ps/er-brac/procguid.pdf

Department of Navy Environmental Program
http://enviro.navy.mil

DON Cleanup Information
http://206.5.146.100/cleanup/index.html

Air Force

USAF Air Mobility Command (AMC) Long-Term Monitoring Optimization Web Site
http://www.amc-ce.org

AFCEE Long-Term Monitoring Optimization Guide
http://www.afcee.brooks.af.mil/er/

Air Force Base Conversion Agency
http://www.afbca.hq.af.mil/

Environmental Site Closeout Process
http://www.afbca.hq.af.mil/closeout/

Air Force Air Combat Command (Site Closure Guidance Manual)
http://www.afbca.hq.af.mil/acc_scgm

Army

Army Environmental Center Environmental Restoration
http://www.aec.army.mil/prod/usaec.er/er.htm

Army Corps of Engineers Checklists
http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html

General DoD

Defense Environmental Network and Information Exchange (DENIX)
http://denix.cecer.army.mil/denix/denix.html

Department of Energy (DOE)

Department of Energy, Office of Environmental Management
http://www.em.doe.gov/index.html

Department of Energy, Environmental Restoration
http://www.em.doe.gov/er/

Data Quality Objectives - Pacific Northwest National Lab
http://terrassa.pnl.gov:2080/DQO/home.html

EPA
Environmental Protection Agency
http://www.epa.gov

Federal Facilities Restoration and Reuse Office
http://www.epa.gov/swerffrr

Miscellaneous
Federal Remediation Technologies Roundtable (FRTR)
http://www.frtr.gov

Hazardous Waste Clean-up Information
http://www.clu-in.org

Ground Water Remediation Technologies Analysis Center
http://www.gwtac.org

Strategic Environmental Research and Development Program
http://www.serdp.org/

10.2 Useful Documents

EPA, *Five-Year Review Guidance*, Second Interim Draft, March 1998.

EPA, *Updating Remedy Decisions at Select Superfund Sites - Summary Report FY96-97*, Groundwater Remedy Updates Presentation by Matthew Charsky, November 1998.

EPA, *Closeout Procedures for National Priority List Sites*, EPA/540/R-95/062, Interim Final, August 1995.

EPA, *Guidance on Preparing Superfund Decision Documents*, EPA/540/G-89/007, Interim Final, July 1989.

DoD, *The Environmental Site Closeout Process*, Interim Document, November 1998.

Air Combat Command, *Installation Restoration Program Site Closure Guidance Manual*, Interim Final, October 1997.

AFCEE, *Long-Term Monitoring Optimization Guide*, October 1997.

EPA, *Methods for Evaluating the Attainment of Cleanup Standards Volume 2*: Ground Water, EPA-R-92-14, July 1992.

EPA, *Guidance for Data Quality Objectives*, EPA/600/R-96/055.

EPA, *Field Sampling and Analysis Technologies Matrix and Reference Guide*, EPA/542/B-98/002.

AFCEE, *Technical Protocol for Implementing Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved-Phase Fuel Contamination in Groundwater*, 1995.

EPA, *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*, September 1998.

EPA, *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*, OSWER Directive 9200.4-17 Interim Final, December 1997.

DoN, *Technical Guidelines for Evaluating Monitored Natural Attenuation of Petroleum Hydrocarbons and Chlorinated Solvents in Groundwater at Naval and Marine Corps Facilities*, September 1998.

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NAVFAC, *Procedural Guidance for Statistically Analyzing Environmental Background Data,* September 1998.

NFESC, *Navy Installation Restoration Chemical Data Quality Manual,* SP-2056-ENV, September 1999.

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Appendix A
Summary of Optimization Case Studies

NWIRP Dallas

FINAL

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT DALLAS LONG-TERM MONITORING DEVELOPMENT CASE STUDY

Prepared for:
Naval Facilities Engineering Service Center
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September 1999

EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study

The main purpose of this case study is to provide: (1) specific guidance and direction to the Naval Weapons Industrial Reserve Plant (NWIRP) in Dallas, Texas, regarding the required elements of a groundwater compliance plan, and (2) recommendations for continual streamlining of a monitoring program. A discussion of closeout strategy for the installation is also presented. In addition, best practices that have been implemented at NWIRP Dallas and may be incorporated into the strategy of other facilities are documented in this case study.

ES.2 Optimization Approach

This case study focuses on ways to reduce the resources expended at NWIRP Dallas for groundwater monitoring without compromising program and data quality. This evaluation includes an assessment of five basic areas:

- The number of monitoring points;
- The efficiency of current field procedures;
- The duration and frequency of monitoring;
- The analyte list and analytical methods; and
- Reporting and data management protocols.

ES.3 Installation and Program Background

NWIRP Dallas is a government-owned, contractor-operated (GOCO) facility located in Grand Prairie, Texas, between Dallas and Fort Worth. It covers 314 acres on the shoreline of Mountain Creek Lake and is adjacent to Naval Air Station (NAS) Dallas, which is now closed. The primary mission of the installation, which was built in 1941, has been military aircraft manufacturing. The installation is currently operated by Northrop Grumman.

Environmental work began at NWIRP Dallas in the 1980s. During a Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA) conducted in the early 1990s, 16 solid waste management units (SWMUs) and 6 areas of concern (AOCs) were identified. The RFA determined that contamination to the groundwater has resulted from activities at these SWMUs and AOCs, which include wastewater treatment, waste and hazardous material storage, waste disposal and incineration, and manufacturing.

An RCRA Facility Investigation (RFI) was conducted from 1993 to 1994. The investigation results indicated that there is one large plume of groundwater contamination by chlorinated solvents and other volatile organic compounds (VOCs) covering 80% of the installation. Consequently, the installation has been treated as one site.

An RCRA Part B permit was issued by the Texas Natural Resource Conservation Commission (TNRCC) to NWIRP Dallas in April 1994. The Part B permit specified that stabilization measures be implemented to stop further off-site migration of the contaminated plume.

ES.4 Best Practices Already in Place

There are several examples of practices that NWIRP Dallas has already put in place to optimize their periodic groundwater monitoring program. The following items may be evaluated by other installations seeking to reduce costs associated with their own long-term monitoring (LTM) or periodic monitoring programs:

- NWIRP Dallas has implemented micropurging to increase sample quality and, in many cases, eliminate metals as chemicals of concern (COCs).
- The installation has analyzed groundwater monitoring data from sampling events, performed trend analysis, and contoured the data to make recommendations for program improvements.
- NWIRP Dallas used geostatistics to demonstrate that 58 monitoring wells could be removed from the program without compromising program quality.
- The installation currently handles all of its data electronically to facilitate data management and visualization.
- NWIRP Dallas proactively initiated a site-wide background study for metals.
- The installation has employed the help of outside government agencies to assist in evaluation and treatment of the contaminated groundwater plume.

ES.5 Site Closeout Strategy

Several strategies for negotiating eventual site closeout should be considered now, as the monitoring program is about to start. These include the following:

- Continue to aggressively pursue the application of monitored natural attenuation (MNA) for the contaminated plume.
- Initiate discussions with TNRCC to establish alternate concentration limits (ACLs) for the groundwater plume, with Mountain Creek Lake as the point of compliance.
- Consider expanding the Stabilization System Performance Evaluation Reports to include graphical presentation of additional cost and performance metrics.
- Initiate discussions with the regulatory agencies to establish measurable decision criteria defining the meaning of technical and/or cost impracticability for NWIRP Dallas.
- Continue to evaluate innovative in situ groundwater treatment remedies as possible cost-effective alternatives to conventional pump and treat for source removal.

ES.6 Monitoring Program Design

On the basis of the optimization strategy summarized in Section ES.2, several suggestions for the design of the monitoring program at NWIRP Dallas are offered:

- Exclude approximately 80% of the installation monitoring points from the monitoring program, using TNRCC guidance to identify those points that should be included.
- Following a year of quarterly sampling, pursue a reduction of sampling frequency to semiannually for point-of-compliance (POC) and corrective action observation wells, and annually for upgradient and background wells.
- Continue using micropurging techniques, but refine the placement of dedicated tubing intakes to ensure purging from the most productive

zones, thus eliminating vertical flow within the wells.

- Decrease the analyte list to VOCs and metals of concern, including hexavalent chromium.
- Pursue coordination of the monitoring database with a geographic information system (GIS) application.
- Focus on graphical and tabular reporting formats and minimize the amount of text submitted in quarterly reports.

TNRCC regulations require that requests for modifications to an issued groundwater compliance plan be submitted following a specific format. These requests must be accompanied by a fee, the amount of which depends on the extent of the proposed modifications. Therefore, it is important to have a thorough periodic evaluation of the monitoring program so that modification requests can be minimized to the extent possible.

ES.7 Benefits

The benefits of applying the above recommendations include a potential cost savings of almost \$130,000 per sampling round, as compared with the cost of sampling all monitoring points for target compound list (TCL) organics and target analyte list (TAL) metals. During the second year of sampling, additional cost savings, estimated at \$65,000 per year, may be realized by decreasing monitoring frequency. The cost associated with requesting a compliance plan modification, including labor, should be substantially less than the amount saved. These estimated savings do not consider additional savings associated with data validation, management, and reporting.

MCB Camp Lejeune

FINAL

MARINE CORPS BASE CAMP LEJEUNE
LONG-TERM MONITORING
OPTIMIZATION CASE STUDY

Prepared for:
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August 1999

EXECUTIVE SUMMARY

ES.1 Purpose of the Plan

The purpose of this case study is to evaluate the monitoring programs for six Operable Units (OUs) at Marine Corps Base (MCB) Camp Lejeune, North Carolina. Specific recommendations to streamline long-term monitoring (LTM) and avoid some of the costs associated with monitoring at the OUs are included in this case study. A discussion of site closeout strategy is also presented. In addition, best practices that have been implemented at the installation and may be incorporated into the strategy of other facilities are documented in this plan.

This case study was conducted for the Naval Facilities Engineering Service Center (NFESC) under a Broad Agency Announcement contract. NFESC is assisting a Department of the Navy working group that will develop guidance on optimizing monitoring and remedial action operations for Navy/Marine Corps activities. This working group is comprised of members from NFESC, Atlantic Division (LANTDIV), other Engineering Field Divisions/Activities, Naval Facilities Engineering Command, and Chief of Naval Operations. The working group selected six OUs at MCB Camp Lejeune for this case study. Similar case studies are also underway at two other Navy facilities. The "lessons learned" and findings from these case studies will be used to develop the guidance document

ES.2 Optimization Approach

The approach used to evaluate and optimize the LTM programs at MCB Camp Lejeune includes an assessment of five basic areas:

- The number of monitoring points;
- The duration and frequency of monitoring;
- The efficiency of current field procedures;
- The analyte list and analytical methods; and
- Reporting and data management protocols.

Section ES.6 summarizes the recommendations for each of these areas.

ES.3 LTM Program at Camp Lejeune

The LTM program at MCB Camp Lejeune currently includes six OUs. There are a total of 13 sites at these six OUs. Nine are included in the LTM program, two required no further action, and one was closed out following a removal action. Another site was removed from the LTM program following several rounds of non-detect (ND) data. By the end of calendar year 1999, it is anticipated that an additional three sites will have been eliminated from the LTM program. It is also anticipated that Records of Decision (RODs) will be put in place during 1999 for two more OUs that will be added to the LTM program.

ES.4 Best Practices Already in Place

There have been several commendable examples of program streamlining in the MCB Camp Lejeune LTM program. These include:

- Use of decision criteria to remove sites from the LTM program;
- Detailed work plans for the entire LTM program;

- Trend analysis and plume contour maps to make recommendations for program improvements;
- Inspection and abandonment of deteriorating wells;
- Semiannual or annual monitoring for the entire LTM program;
- A "team approach" with regulators and the community;
- A streamlined reporting process; and
- Electronic data handling.

ES.5 Site Strategy Considerations

In preparation for the 5-year review, scheduled for calendar year 1999, there are several site strategies to consider. These include:

- Assessing the role of natural attenuation at the LTM sites;
- Tracking cost and performance data for the pump and treat systems at OU Nos. 1 and 2; and
- Pursuing a potential technical impracticability waiver for the pump and treat system at OU No. 2.

ES.6 Recommended Optimization of LTM

Following is a summary of specific recommendations made for the LTM program at MCB Camp Lejeune, based on the optimization approach outlined in Section ES.2.

Monitoring Point Reduction— Although the LTM program for Camp Lejeune includes a reasonable number of wells at each site to achieve program objectives, there are a few wells that may be eliminated from the program without compromising quality. The elimination of five groundwater monitoring wells at OU No. 2 and two surface water and sediment sample locations at OU No. 4 from the LTM program is recommended. In addition, the current policy of regularly inspecting wells and abandoning those found to be in deteriorating condition should be continued as a way to further reduce the number of monitoring points.

Duration and Frequency Reduction—Several of the semiannual monitoring reports discuss the natural occurrence of high levels of metals in groundwater at Camp Lejeune. A small Basewide background metals study is recommended as a potential tool for decreasing the duration of monitoring at sites where metals are contaminants of concern. This strategy may not be necessary for Site 28 (OU No. 7), which may be closed out during calendar year 1999, but may be very helpful in eventually closing out Site 41 (OU No. 4).

Several of the deep wells at OU No. 2 have already been reduced to annual monitoring. Two deep wells at OU No. 1 and one at OU No. 12 may also be reduced to annual monitoring. Reducing the sampling frequency of upgradient or background wells to annual monitoring is another recommended approach for achieving frequency reduction.

Field Procedure Efficiency Improvements—Low-flow purging, or "micropurging", using the stabilization of water quality parameters as the purge criteria, is recommended. Consideration should be given to the installation of a dedicated sampling system to save labor, eliminate the need for equipment blanks, and improve sample quality.

Simplification of Analyses— The analyte list may be significantly simplified by eliminating compounds not detected in four rounds of sampling. In addition, Contract Laboratory Protocol (CLP) metals are being recommended for elimination from the OU No. 2 LTM program by the LTM contractor. A background metals study, recommended as a tool to help close metal-contaminated sites, may also help to eliminate metals from the analyte list at some sites.

Report Streamlining—Camp Lejeune has already made considerable efforts in streamlining the semiannual reporting process. Further streamlining of the reporting effort by decreasing text discussion and consolidating graphic and tabular data is recommended.

Data Analysis—There are currently plans to incorporate the electronic data from the LTM program into the active Geographic Information System (GIS) application for Camp Lejeune. The Base should complete this task as soon as possible so that spatial and other data analysis tools are available for LTM and site closeout decision making. In addition, having a GIS application for the LTM program will significantly improve the quality of presentations to regulators and the public.

ES.7 Benefits

The benefits of applying the above recommendations include a potential annual LTM program cost savings of approximately 18% of the analytical budget, or $6000, and approximately 50% of the field labor budget, or $30,000. These figures do not include all of the possible savings, such as for reporting and data management, and it is estimated that it may take two years to recoup some recommended capital expenditures.

There are additional potential benefits of implementing the suggestions summarized above and detailed within this case study. It is anticipated that data, report, and presentation quality may be improved as a result of some of the recommended monitoring program changes.

NAS Patuxent River

FINAL

NAVAL AIR STATION PATUXENT RIVER LONG-TERM MONITORING OPTIMIZATION CASE STUDY

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August 1999

EXECUTIVE SUMMARY

ES.1 Purpose of the Plan

The purpose of this case study is to evaluate the long-term monitoring (LTM) programs for two sites at Naval Air Station (NAS) Patuxent River, Maryland. Specific recommendations to streamline LTM and avoid some of the costs associated with LTM at the Former and Current Landfills and the Fuel Farm are included in this case study. A discussion of closeout strategy for these sites is also presented. In addition, best practices that have been implemented at the landfills and the fuel farm and may be incorporated into the strategy of other facilities are documented in this plan.

ES.2 Optimization Approach

The approach used to evaluate and optimize the LTM programs at NAS Patuxent River includes an assessment of five basic areas:

- The number of monitoring points;
- The efficiency of current field procedures;
- The duration and frequency of monitoring;
- The analyte list and analytical methods; and
- Reporting and data management protocols.

ES.3 Former and Current Landfills

The Former Landfill is located adjacent to and upgradient from the Current Landfill (Figure 3-1). The Former and Current Landfills are being monitored as one site, and for the purpose of this document will be referred to as "the landfill."

The landfill occupies approximately 16.5 acres in the southern portion of the Base. Disposal operations began at the site in 1974 and continued for approximately 20 years. Contamination of groundwater by organic and inorganic compounds has resulted from site operations. A landfill cap was installed as an interim remedial action (IRA) in 1996-1997 to officially close the site. An adjacent site, Site 34, has evidence of contamination due to drum disposal but has not yet been fully investigated.

The landfill is a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List (NPL) site. An LTM program is being conducted at this site to assess the effectiveness of the landfill cap. This monitoring program includes groundwater, surface water, sediment, leachate, and landfill gas. This case study focuses on the most costly aspect of this program, the groundwater monitoring.

There have been several commendable examples of program streamlining in the landfill IRA, LTM, and performance monitoring programs. These include:

- Using on-site borrow to reduce the construction costs of the landfill cap;
- Negotiating quarterly monitoring instead of the State-proposed monthly monitoring; and
- Exploring contracting options and mechanisms to identify potential cost savings.

ES.3.1 Recommendations

Following an assessment of the landfill and associated documents, recommendations regarding site closeout, LTM strategy, and landfill cap performance monitoring were formulated.

Site Closeout—In preparation for the 5-year review of the LTM program, several things should be considered:

- In anticipation of the final Record of Decision (ROD) for the site, the Base should identify decision criteria for determining when monitoring at the site, or for a specific monitoring point, may be stopped.
- Several rounds of natural attenuation data may be instrumental in convincing regulators that no active remediation is necessary at the landfill or Site 34. A program to collect such data should be considered.
- Combined monitoring of groundwater at the landfill and Site 34 should be investigated, in case the State requires an LTM program at Site 34. Combining these sites is likely to reduce the overall number of monitoring wells in the program.
- Cost and performance data for the flare system should be tracked to continually assess site progress and prepare for the 5-year review.
- Contaminant trends in groundwater should be tracked to continually assess site progress and prepare for the 5-year review.

Long-Term Monitoring— Following is a summary of specific recommendations made for the LTM program at the landfill:

- Consider eliminating two or three wells from the LTM program this year. Conduct a statistical analysis next year to determine if additional wells may be eliminated.
- Pursue a reduction to semiannual monitoring with regulators following the reporting of four quarters of data.
- Investigate the potential for using micropurging techniques by determining if well recharge is adequate. If so, consider installation of a dedicated sampling system to save labor, eliminate equipment blanks, and improve sample quality.
- Reduce the analyte list by eliminating compounds not detected in the first year of sampling. Also, consider eliminating dissolved metals and decreasing QA/QC sample rates.
- Take advantage of the service contract in place to provide geographic information system (GIS) and electronic data handling support. With this support, use data analysis tools to enhance decision-making.
- Streamline the reporting effort by focusing on graphic and tabular data presentations and consolidating all reports for a year in one binder.

Performance Monitoring— Although an in-depth assessment of landfill cap performance monitoring was not made, there is one recommendation for improving the efficiency of weekly landfill gas monitoring. By modifying the sampling ports so that they can be accessed from the surface, rather than by entering the vaults in which they are currently housed, sampling time can be decreased. In addition, the safety of the operation will be increased.

ES.3.2 Benefits

The benefits of applying the above recommendations include a potential LTM program cost savings of over 25% of the current budget, prior to reducing sampling frequency from quarterly to semiannually. In addition to the cost savings, adopting these recommendations has the potential to improve data and report quality as well as sampling personnel safety.

ES.4 The Fuel Farm

The fuel farm occupies more than 12 acres in the northwest portion of the Base. Fuel handling operations began at the site in the early 1940s but are inactive today. Possible leaks from tanks and pipelines have resulted in the contamination of soil, groundwater, and surface water. Several investigations and technology demonstrations have taken place at the site from the late 70s to the present.

The fuel farm is an underground storage tank (UST) site and falls under State of Maryland UST regulations. Groundwater sampling has been conducted in some or all of the site's 90 wells nine times since 1984. A tank and soil removal action took place early in calendar year 1999 and a formal LTM program has been started at the fuel farm.

NAS Patuxent River has been proactive in assessing innovative remedial actions for the fuel farm. As a result of these assessments, viable remedial alternatives, such as mobile bioslurping and a pump and treat system, have been implemented. In addition, a significant amount of data that could be used to support a natural attenuation remedy have been collected.

ES.4.1 Recommendations

Following an assessment of the fuel farm and associated documents, recommendations regarding site closeout, LTM program design, and system performance monitoring were formulated.

Site Closeout—Several strategies for negotiating eventual site closeout should be considered now that the removal action and first round of monitoring has been completed:

- Several bioremediation studies have been conducted at the site, with promising results. Additional natural attenuation data should be collected to support decisions to shut down active treatment systems when appropriate.
- Decision criteria should be formulated now so that decisions regarding shutting down remedial systems, stopping monitoring, and closing out the site can be made when appropriate.
- Collection of cost and performance data for the treatment system and contaminant trends in groundwater should be tracked to continually assess site progress and support a possible natural attenuation remedy.

Long-Term Monitoring—Following is a summary of specific recommendations made for the upcoming LTM program at the fuel farm:

- Eliminate 60% of the site wells from the fuel farm LTM program. Continue to assess the potential for eliminating additional wells on an annual basis.
- Investigate the potential for using micropurging techniques by determining if well recharge is adequate. If so, consider installation of a dedicated sampling system to save labor, eliminate equipment blanks, and improve sample quality.
- Pursue an appropriate sampling frequency for wells remaining in the LTM program to limit costs and facilitate trend analysis.
- Pursue an appropriate analyte list for site contaminants, focusing on specific analytes of regulatory significance.
- Take advantage of the service contract in place to provide GIS and electronic data handling support. With this support, use data analysis tools to enhance decision-making.

- Streamline the reporting effort by focusing on graphic and tabular data presentations and consolidating all reports for a year in one binder.

Performance Monitoring— Although an in-depth assessment of system performance monitoring was not made, there are a few recommendations for improving this task. These are to:

- Track contaminant mass removal and cost per pound data to support decisions regarding future shutdown of active remedial systems;
- Conduct bail-down tests so that true product thickness can be determined; and
- Better define the potentiometric surface at the site.

ES.4.2 Benefits

Eliminating over 60% of the wells at the site from the LTM program design will decrease the LTM budget by approximately the same percentage without compromising the quality of the program. Other benefits of the suggestions cited for the fuel farm include the potential for earlier shutdown of active remedial systems, via a natural attenuation alternative, and improved data and report quality.

Appendix B
Navy Internal Case Studies

MCLB Albany

MCLB Albany, GA

CASE STUDY

Ground Water Monitoring Optimization

Industrial Wastewater Treatment Plant Sludge Drying Beds Ground Water Monitoring

Summary

The Navy, in conjunction with regulators, reduced the sampling frequency at a former sludge drying bed site at Marine Corps Logistics Base (MCLB) Albany from quarterly to semiannually. In addition, the Navy changed the contract type from a cost plus to a fixed price contract and significantly decreased the number of contractor maintenance visits. These actions have saved the Base nearly $250,000 in long term monitoring/remedial action operation (LTM/RAO) costs annually. MCLB Albany is currently investigating the possibility of ceasing pump and treat operations and including this site in a broader ground water management program to further optimize the cost effectiveness of the program.

1.0 Site Background

1.1 Site History

Marine Corps Logistics Base (MCLB) Albany is located approximately 192 miles south of Atlanta and 225 miles northwest of Jacksonville, Florida. Because MCLB Albany includes a depot maintenance facility, large quantities of industrial wastewater are generated from various industrial processes such as degreasing, paint stripping, and electroplating. All of the industrial wastewater is treated at the Base's Industrial Wastewater Treatment Plant (IWTP).

The IWTP began operations in 1977 and remains in service today. Initially, the plant pretreated industrial wastewater, which was then routed to the Base's Domestic Wastewater Treatment Plant (DWTP). The Base DWTP was closed in 1990, and the IWTP currently discharges to the City of Albany DWTP.

Three sludge drying beds associated with the IWTP leaked chlorinated solvents and metals to underlying soil and ground water. These drying beds were closed in 1987, following approximately 10 years of service. At the time of closure, 3 to 4 feet of soil was removed under the beds. The excavation was then backfilled with clay and capped with 12 inches of concrete.

A pump and treat system has been in operation at the site since January 1990. This system initially had three recovery wells, and an additional three wells were added in February 1995.

There is a trichloroethylene (TCE) plume in ground water at the site, with concentrations ranging up to 44 μg/L. TCE is the only compound above regulatory limits, and concentrations appear to be stabilizing. Upgradient ground water at this site has higher concentrations of TCE than measured in site monitoring wells.

1.2 Site Geology and Hydrogeology

MCLB Albany is located within the coastal plain of Georgia. The coastal plain sediments underlying the Albany area consist of alternating layers of sand, clay, shale, and limestone, which exhibit lateral variations in thickness and lithology. The uppermost water-bearing formations that underlie the sludge drying bed site are the Residuum and the Ocala Limestone. The Residuum is the weathered portion of the Ocala Limestone, and consists of reddish-brown sandy, silty clay with residual limestone. The Residuum varies in depth below surface from approximately 60 to 100 feet across the site. The Ocala Limestone is variably fine to coarse grained, chalky, and fossiliferous (Hicks, et al., 1981). Recovery wells are screened at the bottom of the Residuum.

The Ocala aquifer is recharged primarily by the infiltration of rainfall through the Residuum. This aquifer is generally confined wherever it is overlain by Residuum. Seasonal fluctuations within the Ocala result from higher precipitation and lower evapotranspiration rates in the winter months. Increased pumping for irrigation in the summer months also contributes to the seasonal fluctuations. Although the regional ground water flow for the Ocala Aquifer is to the south, ground water flow in the area of the sludge drying beds is to the west. Ground water flow direction in the area of MCLB Albany is influenced by the Flint River, located to the west.

2.0 Program Status

The sludge drying beds are in RAO status, and are being remediated under the Resource Conservation and Recovery Act (RCRA). Ground water at the site has been monitored since 1994, and has been on a semiannual schedule since 1997. Reporting for the LTM program is also done on a semiannual basis.

3.0 LTM Program Summary

3.1 Initial Program

The initial ground water monitoring program included 11 monitoring wells, which were sampled quarterly and analyzed for 23 parameters. The ground water monitoring network for the site included a background well and 10 “point of compliance” (POC) wells.

3.2 Current Program

Under the current RCRA post-closure permit, the same 11 monitoring wells specified in the original permit are required to be sampled semiannually and analyzed for nine parameters.

4.0 Contaminants

Site contaminants consist primarily of chlorinated solvents and metals. Currently, only TCE exceeds regulatory limits, and concentrations of this compound have declined and stabilized over time. Ground water samples from the site were initially analyzed for a total of 23 constituents, but in 1997 the Navy in conjunction with the State decreased the number of site analytes to nine. The current analyte list for the site is:

- pH
- Specific conductance
- 1,1-Dichloroethane
- 1,1-Dichloroethylene
- 1,2-Dichloroethylene
- Cis 1,2-Dichloroethylene
- 1,1,1-Trichloroethane
- Trichloroethylene
- Total Xylenes

5.0 Ground Water Monitoring Network

A total of 16 monitoring wells and six recovery wells have been installed at the sludge drying beds site. Figure 1 shows a map of the site, including the monitoring and recovery well network. Table 1 shows the wells required to be monitored by the current RCRA post-closure permit.

6.0 Contract Type

The contract under which the ground water monitoring program is being performed is an indefinite quantity fixed price contract.

Table 1. Monitoring Wells in the Ground Water Monitoring Program

	Background	Point of Compliance
Wells Required by RCRA Post-Closure Permit	MW-15	MW-2, MS-3, MW-4, MW-4B, MW-5, MW-6, MW-6A, MW-7, MW-17, P6
Other Site Monitoring Wells	MW-1, MW-10, MW-11, MW-13, MW-14	

7.0 Cost of Ground Water Monitoring

The annual cost of the LTM program in 1995 was $351,040. In 1998, the annual cost was $102,280, reflecting annual savings of approximately $250,000.

8.0 What Prompted Review of LTM at the Site?

As levels of contaminants decreased in the ground water, the Navy and the State of Georgia agreed that the monitoring effort could be reduced. Recommendations to decrease monitoring frequency and modify the RCRA permit were supported by site data.

9.0 Actions Taken To Reduce Long Term Ground Water Monitoring Costs

The following actions were taken to reduce LTM costs associated with the site:

- Change the contractor being used, and change the contract type from cost plus to fixed price.
- Reduce the frequency of sampling from quarterly to semi-annually.
- Decrease operation and maintenance of RAO from weekly to quarterly, and allow for two emergency service visits.
- Decrease the number of analytes from 23 to nine.
- Shift some of the routine monitoring tasks for the pump and treat system away from contractor personnel to Base personnel.

10.0 Regulator Interface

Although there were some growing pains when MCLB Albany transitioned to a new LTM contractor; the Base, current contractors, and the State have now established a cooperative working relationship. It has been the MCLB and the State's cooperative initiative to reduce the amount of monitoring being performed at the sludge drying beds.

Ground water data for the site supported a reduction in monitoring around the sludge drying beds. Site contaminant levels were decreasing asymptotically to near the ground water standards, but it appeared that the rate of reduction from pumping and treating ground water was slowing significantly. When MCLB Albany's permit was up for renewal, the State suggested that the LTM contractor include recommendations in their next report for streamlining the program. As a result, the LTM permit requirements were significantly reduced. The State and the Navy are currently looking at an integrated Basewide LTM program to more effectively manage ground water. This will further improve the overall understanding of ground water quality in a more cost-effective manner.

11.0 Other Actions Being Considered

Other actions being considered to further optimize the LTM program at the site include:

- Ceasing operation of the pump and treat system—this could save approximately $25,000, or nearly 25 percent of the RAO/LTM budget, annually.

- Including this site in a broader ground water management strategy—this could result in "economy of scale" cost savings.

12.0 Contact Information

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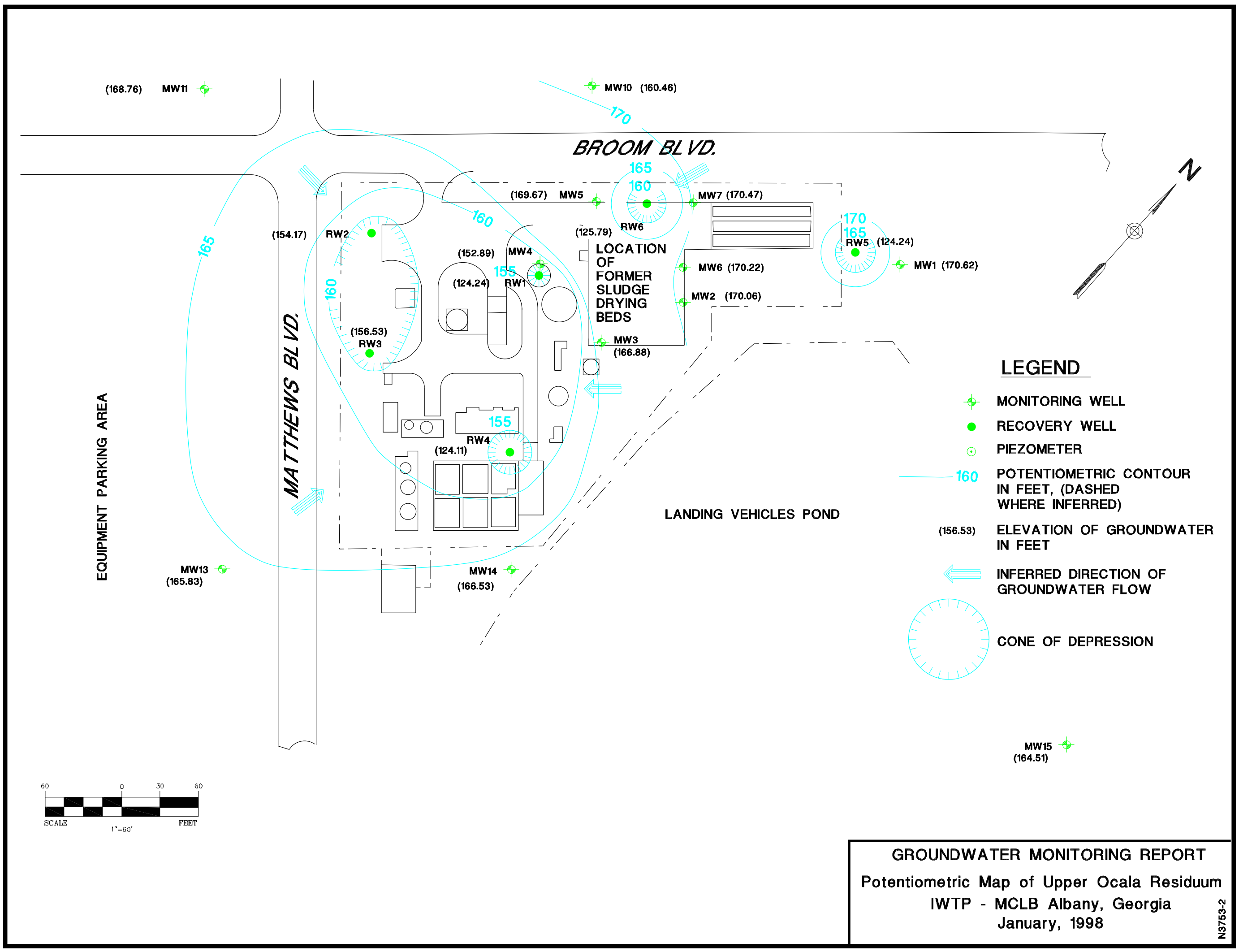

Figure 1. Monitoring Well Network for the Sludge Drying Beds

NAS Brunswick

Naval Air Station, Brunswick, ME

CASE STUDY

Ground Water Monitoring Optimization

Eastern Plume Ground Water Monitoring

Summary

The Navy has been spending approximately $550,000 a year for the ground water monitoring of an existing plume of chlorinated organic compounds at the Naval Air Station (NAS) in Brunswick, Maine. The Navy, the Environmental Protection Agency (EPA) Region I, Maine Department of Environmental Protection (DEP), and the Restoration Advisory Board (RAB) reduced the number of wells to be sampled and the sampling frequency, which will cut annual spending nearly in half. They employed statistics and Data Quality Objective (DQO) principles to achieve this price reduction and efficiency.

1.0 Site Background

1.1 Site History

The "Eastern Plume" at NAS Brunswick has been attributed to past solvent disposal practices from three Installation Restoration Program (IRP) Sites: a former fire fighter training area, a Defense Reutilization and Marketing Office (DRMO) Area scrap yard, and a former acid/caustic waste pit. The plume consists primarily of chlorinated organic compounds including trichloroethene (TCE), perchloroethene (PCE), 1,1,1-trichloroethane (TCA), and limited breakdown products. The Eastern Plume is in the Remedial Action Operations (RAO) phase. An interim record of decision (ROD) for extraction and treatment was signed in June 1992, and a Final ROD for No Further Action for soils and continued pump and treat operation for ground water was signed in February 1998.

Preliminary subsurface investigations were completed at the Fire Training Area (FTA) in 1989. The FTA reportedly has been active since the 1950's. Various fuels, oils, and miscellaneous solvents have been used for multiple annual burns during this 40- to 50-year period. These contaminants have percolated into the unsaturated soils and leached downward to the ground water table, forming a plume of contaminated ground water. Ground water contamination consists primarily of volatile organic compounds (VOCs). Total VOCs detected in four wells at the FTA range from 137 to 821 μg/L. Fire training exercises have been discontinued at the Base.

The DRMO Area was added to the IRP upon completion of the 1988 Remedial Investigation (RI) field work. Ground water contamination consists of elevated levels of chlorinated VOCs and trace levels of BTEX (benzene, toluene, ethylbenzene, and xylene) compounds. Ground water contamination appears to have resulted from leaking underground storage tanks (USTs) used for waste solvents and fuels. Two former waste-liquid USTs were removed within the past several years.

The Acid/Caustic Disposal Pit is located beneath the eastern end of the active DRMO. The Acid/Caustic Disposal Pit was a small hole in the ground into which liquid wastes were disposed of from approximately 1969 to 1974. Wastes reportedly included transformer oils, petroleum products, paints, and solvents. No soil contamination has been detected in borings near the former pit, and only low levels of TCE have been detected in the ground water immediately downgradient of the pit, which is no longer a significant source of contamination.

Ground water from the Eastern Plume site has been extracted and treated since 1995 and discharged to the local sewer authority. Five extraction wells were installed along the eastern perimeter of the Eastern Plume site to provide hydraulic control of the VOC plume and remove dissolved-phase VOC from ground water. The extraction wells are screened through the shallow and deep zones of the overburden aquifer and are plumbed to a central treatment plant located north of the Eastern Plume site.

1.2 Site Geology and Hydrogeology

The geology underlying the Eastern Plume area consists of three overburden units overlying bedrock. The shallow sand unit is approximately 10 to 20 feet thick and consists of fine sand. The transition unit separates the shallow sand unit from the underlying clay, and is composed of interbedded sands, silts, and clays. Sands within the transition unit, which ranges in thickness from 5 to 80 feet, act as preferential flow paths for ground water. The Presumscot clay formation is a low permeability clay unit, ranging from 20 to 60 feet thick, overlying the bedrock surface. Bedrock in the area consists of micaceous schist, which does not appear to be heavily fractured.

Ground water occurs beneath the site in both the overburden units and the bedrock. Monitoring wells in the Eastern Plume area are completed at two different intervals within the overburden units. Shallow wells are installed in the shallow sand and upper transition unit (up to 40 feet below ground level). Deep wells are installed in the lower transition unit. Potentiometric surface information from the monitoring wells indicates that the shallow overburden aquifer is unconfined, whereas the deep overburden aquifer is semi-confined. Ground water in the shallow overburden aquifer generally flows to the east-southeast, and is influenced by surface water drainages. Ground water in the deep overburden aquifer flows generally to the south.

2.0 Program Status

NAS Brunswick is a National Priorities List (NPL) site on the EPA 2000 list, with a goal to have all Final RODs signed by the year 2000. A Final ROD has been in place for the Eastern Plume since February 1998.

Monitoring has been conducted tri-annually since 1995 throughout the Eastern Plume site. However, starting in 1999, the sampling will occur on a semi-annual basis. Annual reports have been completed for NAS Brunswick for calendar years 1995, 1996, and 1997.

3.0 LTM Program Summary

3.1 Initial Program

The initial ground water monitoring program included 36 monitoring wells. Of these, 30 were located within the plume, and six were sentinel wells. The monitoring wells were sampled on a tri-annual basis for VOCs and tentatively identified compounds (TICs).

3.2 Current Program

The current Long-Term Monitoring (LTM) program at NAS Brunswick includes 22 monitoring wells. Of the 22 monitoring wells, 13 are located within the plume and nine are sentinel wells. These wells are monitored for seven VOCs, which represent the contaminants of concern for the site. Starting in calendar year 1999, these wells will be sampled on a semiannual basis.

4.0 Contaminants

The current ground water monitoring plan requires monitoring for the following constituents:

- 1,1-Dichloroethane (DCA)
- 1,1-Dichloroethene (DCE)
- cis-1,2-Dichloroethene
- trans-1,2-Dichloroethene
- Tetrachloroethene
- 1,1,1-Trichloroethane (TCA)
- Trichloroethene (TCE)

5.0 Ground Water Monitoring Network

A total of 73 wells and piezometers have been installed within the Eastern Plume site. All wells at the site are gauged to determine potentiometric surface, and a subset of these wells is used to track the effectiveness of the pump and treat system and plume movement. Figure 1 shows the distribution of deep and shallow wells at the site.

6.0 Contract Type

The contract under which the ground water monitoring program is performed is a Navy CLEAN contract, cost plus award fee.

7.0 Cost of Ground Water Monitoring

The annual cost for LTM for 1996 and 1997 was approximately $550,000. It is anticipated that with the implemented changes to the LTM, there will be several cost reductions throughout the monitoring procedure. These reductions include a 33 percent cost reduction in sampling mobilizations and events and a 40 percent cost reduction in sample collection, analyses, and reporting. In addition, the number of reports will be reduced from seven to four per year, which will reduce the cost of paper by 80 percent. Overall, the LTM program is expected to cost approximately $250,000 per year (down from $550,000). The other IRP sites are smaller in scale, but are also estimated to have a cost reduction of approximately 50 percent.

8.0 What Prompted Review of LTM at the Site?

Review of annual reports and results of geostatistics showed redundant and predictable data. The amount of public participation at this Base also increased the number of copies for distribution (23) for each draft and final report. Comments requiring responses are generally received from at least three entities.

9.0 Actions Taken to Reduce Long Term Ground Water Monitoring Costs

The Navy performed a geostatistical analysis of the monitoring program for the Eastern Plume. It identified a number of data surplus areas and some data gaps. The Navy, EPA, and DEP met for 3 days and reviewed each sampling location. Trends of each well were analyzed and discussed using the DQO process. This meeting also discussed similar LTM issues at three other sites, which are not discussed here. The results of the meeting will be included in the rewritten LTM program for each site.

The following actions have been taken to increase the cost effectiveness of the LTM program:

- Monitoring was reduced from three to two times per year. The number of wells to be sampled was reduced from 36 to 22. Of those 22 monitoring wells, 13 will be in-plume wells and 9 will be sentinel wells.
- Monitoring reports will contain data only; limited discussion will detail field changes from the LTM program.
- Only the annual reports will contain a discussion of contaminant trends. With this presentation, comments on monitoring reports should be limited or nonexistent. This will eliminate the need for comment resolution and consequently a draft report.
- In addition, the option was proposed to deliver the monitoring reports on CD-ROM versus hard copy. This was well received by the community, and will reduce hard copies from 23 to 5.
- Five new monitoring wells will be installed and sampled to fill data gaps. These five wells are included in the 22 total to be sampled.
- The analysis and reporting of TICs has been eliminated.

10.0 Regulator Interface

Regulator involvement was part of the process from the very start. The Navy suggested that a geostatistical analysis be accomplished on the Eastern Plume. Since some of the regulators were unfamiliar with the process, they were invited to attend the same geostatistical training that the Navy personnel had attended. This fostered familiarity and trust with the process.

Because there was still some hesitancy on the part of the regulators to accept the changes recommended for the LTM program on the basis of the geostatistical analysis, the DQO and decision-making processes were discussed in further detail. The regulators' concern continued, stemming from the perception that it was the Navy's goal only to reduce the LTM program without regard to its quality. A data review meeting was held with the single goal of improving the LTM program. The Navy was confident that the end result would be a net reduction in LTM.

At the meeting, the DQO process was used to assess the purpose of each well. Questions regarding the necessity and purpose of the data, as well as what decisions the data would support, were asked for each well. If no reasonable answers could be given for a well, it was eliminated from the LTM program. The same process was applied to additional wells proposed by regulators or the RAB. If a new well was deemed appropriate, using this process, it would be installed and added to the program.

Although initially hesitant, regulators kept an open mind in revising the LTM plan. By the end of the 3-day meeting, all attendees involved were properly implementing the DQO process to suggest wells to be removed from the LTM program. Whether meeting attendees agreed with the formal DQO process, or considered it to be simply common sense, the result was an improved LTM program at NAS Brunswick.

11.0 Other Actions Being Considered

The following additional actions are being considered to further optimize the LTM program:

- The geostatistics showed the plume to be stable. The Navy may consider a discussion of natural attenuation for a 5-year review. This would, however, increase the short term sampling/analysis needs.

- The treatment system at the plant is being reviewed. The UV-Oxidation system treats TCA only to a level suitable for discharge to the sewer. However, if the Navy can better treat the TCA, the water can be discharged to surface water streams or to infiltration galleries. Surface or subsurface discharge would be cost effective because the annual sewer discharge fee is $300,000.
- New extraction wells are being considered. The existing wells are screened over the entire aquifer (60 feet), while the contamination is concentrated in the lower 20 feet. A new extraction well has been installed and is screened in the deep portion of the aquifer only. This well has greatly increased contaminant mass removal with limited flow increase.
- The EPA is also interested in discussing easing the required analytical precision for in-plume samples so that the Navy may explore the economic feasibility of installing an on-site VOC analytical capability. This could allow for more continuous, possibly in-line, sampling of plume and treatment plant conditions. This information could be used in a near real-time manner by the plant operators to optimize contaminant mass removal by the extraction/treatment system and thus more quickly achieve cleanup goals.

12.0 Contact Information

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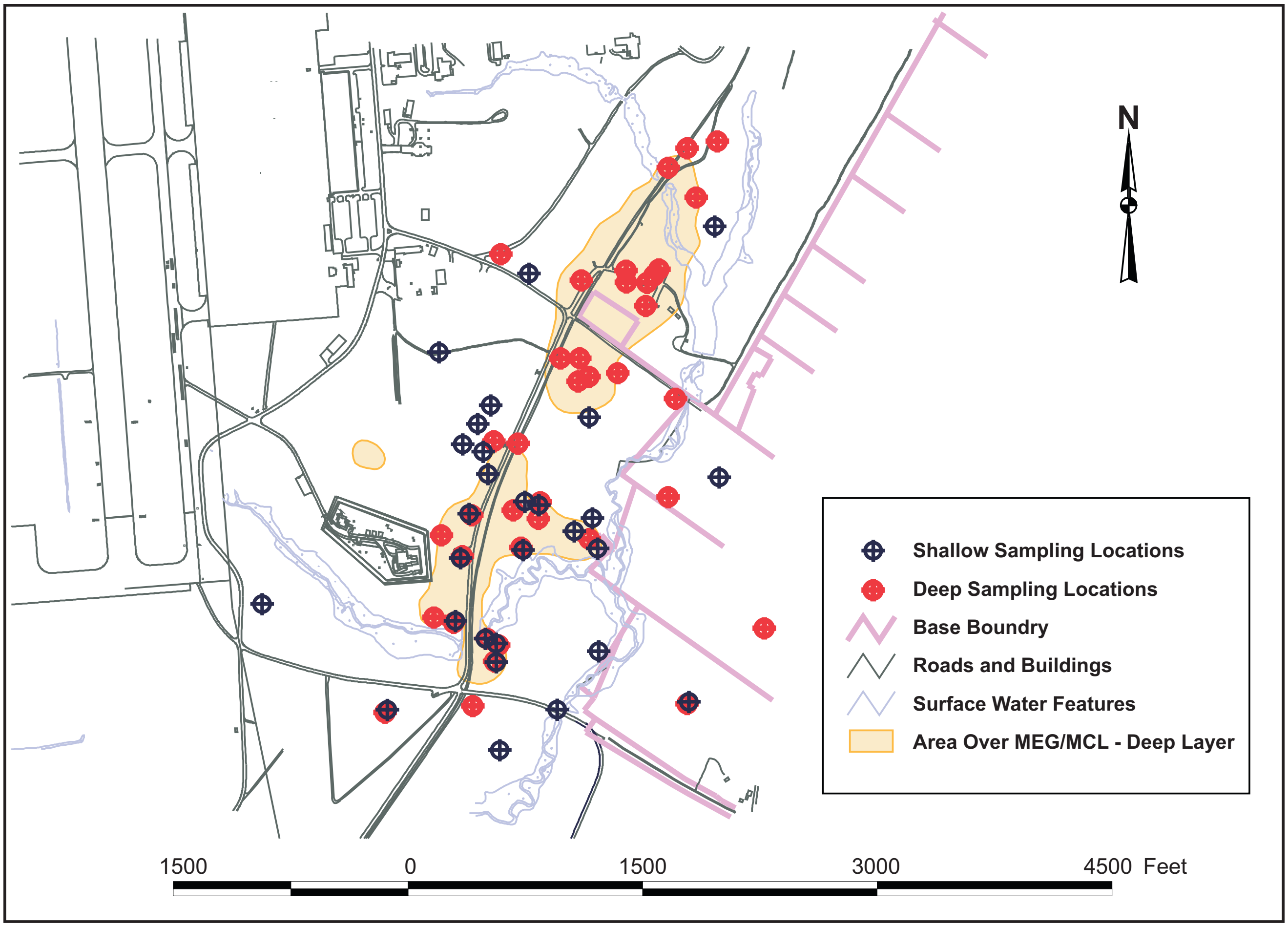

Figure 1. Eastern Plume Monitoring Well Network

NAS Pensacola

CASE STUDY

Ground Water Monitoring Optimization

NAS Pensacola, FL

Sludge Drying Beds/Surge Pond Ground Water Monitoring

Summary

The Navy, in conjunction with regulators, reduced the sampling frequency at a former sludge drying bed and surge pond site at Naval Air Station (NAS) Pensacola from quarterly to semiannually. The number of monitoring wells was reduced from 19 to 15. In addition, the Navy changed the contract type from a cost plus to a fixed price contract. These actions have saved the Navy over $200,000 in annual monitoring costs. NAS Pensacola is currently investigating natural attenuation, hot spot source reduction, and the possibility of ceasing pump and treat operations to further optimize the cost effectiveness of the program.

1.0 Site Background

1.1 Site History

NAS Pensacola occupies approximately 5,800 acres on a peninsula in southern Escambia County, 5 miles south of the city of Pensacola, Florida. The former sludge drying beds and surge pond were located on a peninsula in the northeast corner of the NAS. These units are associated with the former industrial wastewater treatment plant (IWTP), now a wastewater treatment plant (WWTP), that received wastewater from activities on NAS property, including aircraft maintenance and metal plating.

Materials such as degreasers and paint strippers were leaked from various sources at NAS Pensacola, resulting in contamination of the sludge drying beds and surge pond. Consequently, soil and ground water in the area of the IWTP was contaminated by chlorinated solvents and other compounds.

In July 1986, the Environmental Protection Agency (EPA) conducted an inspection of the IWTP for compliance with the Resource Conservation and Recovery Act (RCRA). On the basis of this inspection, the EPA determined that the Navy Public Works Center was operating its IWTP in violation of regulatory and statutory requirements of RCRA. In November 1986, NAS Pensacola received a Notice of Violation (NOV) from the waste compliance section of the EPA Region IV. This NOV resulted in the closure of the sludge drying beds in 1987, on the basis that they had been receiving listed wastes (spent solvents). Following closure of the sludge drying beds, waste was dewatered to a solid state, containerized, and disposed of as a listed waste. The surge pond was closed in 1988, following installation of two aboveground surge tanks.

A ground water treatment system with seven recovery wells was activated at the site in February 1987 to contain the plume and treat ground water contamination. Ground water from the extraction wells was initially treated at the IWTP. Construction of an airstripper treatment system was begun in October 1995 to treat contaminated ground water that could no longer be sent directly to the domestic-waste-only treatment plant.

A soil removal action was conducted in 1989. Contaminated soils were excavated down to the water table. The sludge beds were removed, and the site was covered with an asphalt cap. The surge pond area was excavated and backfilled with clay.

1.2 Site Geology and Hydrology

Subsurface geology at the site consists primarily of homogeneous fine to medium grained sand. A gray clay layer was encountered between 40 and 60 feet below ground level (ft bgl) in most of the intermediate (36 to 48 ft bgl) and deep (65 to 70 ft bgl) monitoring wells. Shallow ground water monitoring wells (10 to 20 ft bgl) are all completed in fine to medium grained sand.

The ground water aquifer underlying the site is divided into three zones, corresponding with the three depths of monitoring wells. These zones display varying hydraulic gradients and conductivities, as well as flow directions and rates. Overall, site ground water flow is toward Pensacola Bay, which borders the site to the east. The depth to ground water is less than 5 ft bgl in some parts of the site.

2.0 Program Status

The sludge beds and surge pond are being remediated under RCRA. NAS Pensacola was placed on the National Priorities List (NPL) in December of 1989, and a Federal Facilities Agreement (FFA) was signed in October of 1990.

Ground water at the site has been monitored since 1990, and has been on a semiannual schedule since January 1992. Reporting for the monitoring program is also done on a semiannual basis.

3.0 Monitoring Program Summary

3.1 Initial Program

The initial ground water monitoring program included 19 monitoring wells, which were sampled quarterly and analyzed for 119 parameters. The ground water monitoring network for the site included a background well, nine “point of compliance” (POC) wells, and ten assessment wells.

3.2 Current Program

Under the current RCRA post-closure permit, 15 monitoring wells are required to be sampled semiannually and analyzed for 119 parameters. However, arsenic, vanadium and four radionuclides are analyzed only yearly. The current ground water monitoring network at the site consists of a background well, eight POC wells, and six assessment wells.

4.0 Contaminants

Site contaminants consist primarily of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals resulting from the handling of hazardous materials at NAS Pensacola. Ground water samples from the site are analyzed for a total of 119 constituents, as outlined below (EPA analytical method in parentheses):

- VOCs (8260)
- SVOCs (8270)
- Metals (6010)
- Arsenic (7060)
- Lead (7421)
- Mercury (7470)
- Selenium (7740)
- Chloride (325.2)
- Fluoride (340.2)
- Sulfate (9036)
- Nitrate (325.1)
- Complexed cyanides (9012)
- Gross alpha (900.0)
- Gross beta (900.0)
- Radium-226 (903.1)
- Radium-228 (904.0)
- Turbidity (180.1)
- pH (150.1)
- Specific conductance (120.1)
- Total coliform (909A)

5.0 Ground Water Monitoring Network

A total of 49 wells have been installed in the vicinity of the sludge drying beds and surge pond. Currently, 15 wells are sampled as part of the monitoring program and 20 of the remaining wells are used for determining ground water flow gradient. Attached are maps of the shallow (Figure 1) and intermediate (Figure 2) monitoring well networks. Table 1 shows the initial and current wells included in the ground water monitoring program.

6.0 Contract Type

The contract under which the ground water monitoring program is being performed is an indefinite quantity fixed price contract.

7.0 Cost of Ground Water Monitoring

The annual cost of the monitoring program in 1992 was $302,370. In 1998, the annual cost was $101,615, reflecting an annual savings of over $200,000 from monitoring improvements.

8.0 What Prompted Review of Monitoring at the Site?

The Navy felt that the ground water monitoring approach was excessive and not cost effective, and began reviewing site history and data in the spring of 1996 to identify an alternative approach. In addition to monitoring improvements, it was determined that natural attenuation (under both aerobic and anaerobic conditions) and hot spot source reduction should be evaluated to optimize the remedy.

9.0 Actions Taken To Reduce Ground Water Monitoring Costs

The following actions were taken to reduce monitoring costs associated with the site:

- Change of contractor and contract type from cost plus to fixed price.
- Reduce the frequency of sampling from quarterly to semi-annually.
- Reduce the number of monitored wells from 19 to 15.
- Shift some of the routine maintenance tasks for the pump and treat system away from contractor personnel to Base personnel.

10.0 Regulator Interface

State regulatory oversight of the sludge drying beds and surge pond monitoring program has been ongoing. When the RCRA permit was due for renewal in 1996, Southern Division technical personnel proposed an enhanced ground water management strategy based on the first year's results of an ongoing natural attenuation assessment. Natural attenuation and source reduction were proposed to be further evaluated as remedial alternatives for the site. The Navy requested a 1-year shutdown of the

Table 1. Initial and Current Monitoring Wells in the Ground Water Monitoring Program.

	Background	Point of Compliance	Assessment
Initial (19 wells total)	UG-1	PCS-1, PCI-1, PCD-1, GM-8, GM-9, GM-10, GM-68, GM-69	GM-62, GM-63, GM-64, GM-65, GM-66, GM-67, GM-11, GM-12R, GM-13, GM-14
Current (15 wells total)	UG-1	PCS-1, PCI-1, PCD-1, GM-8, GM-9, GM-10, GM-68, GM-69	GM-65, GM-66, GM-67, 33G12, 33G16, 33G20

pump and treat system to verify the effectiveness of natural attenuation and to perform source reduction of chlorinated VOCs in ground water with chemical oxidation (Fenton's Reagent). As part of the revised permit negotiations, the number of monitoring wells was reduced and constituents that had not been detected for several years were eliminated from the monitoring analyte list.

11.0 Other Actions Being Considered

Based on the successful results of the chemical oxidation source reduction completed in June 1999 and the verified effectiveness of natural attenuation, Southern Division NAVFAC is currently preparing a Corrective Action Plan and permit modification to propose permanently discontinuing the pump and treat system and establish monitored natural attenuation as the final remedy.

Discontinuing the unnecessary pump and treat system will save an additional $25,000 annually.

12.0 Contact Information

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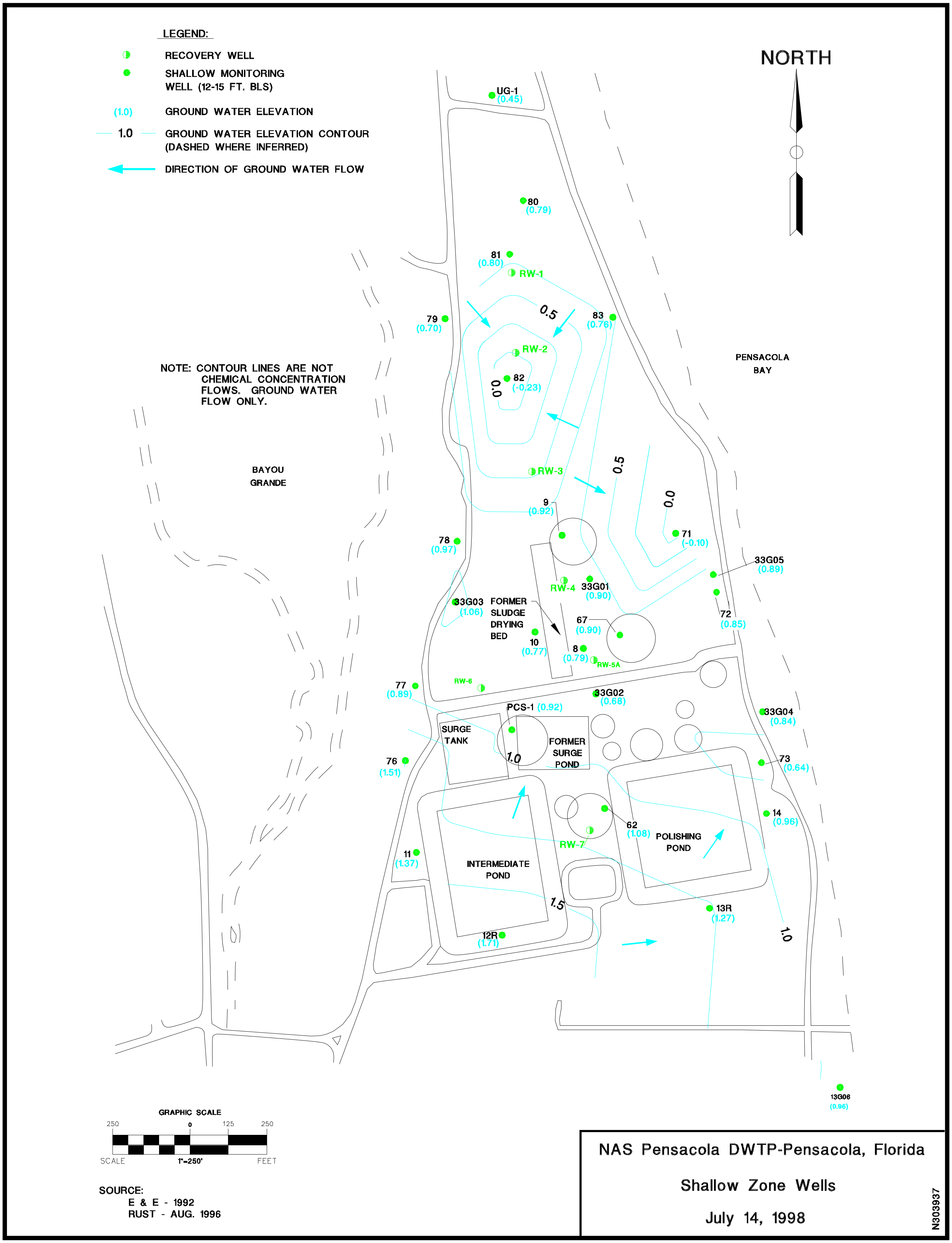

Figure 1. Shallow Zone Monitoring Well Network

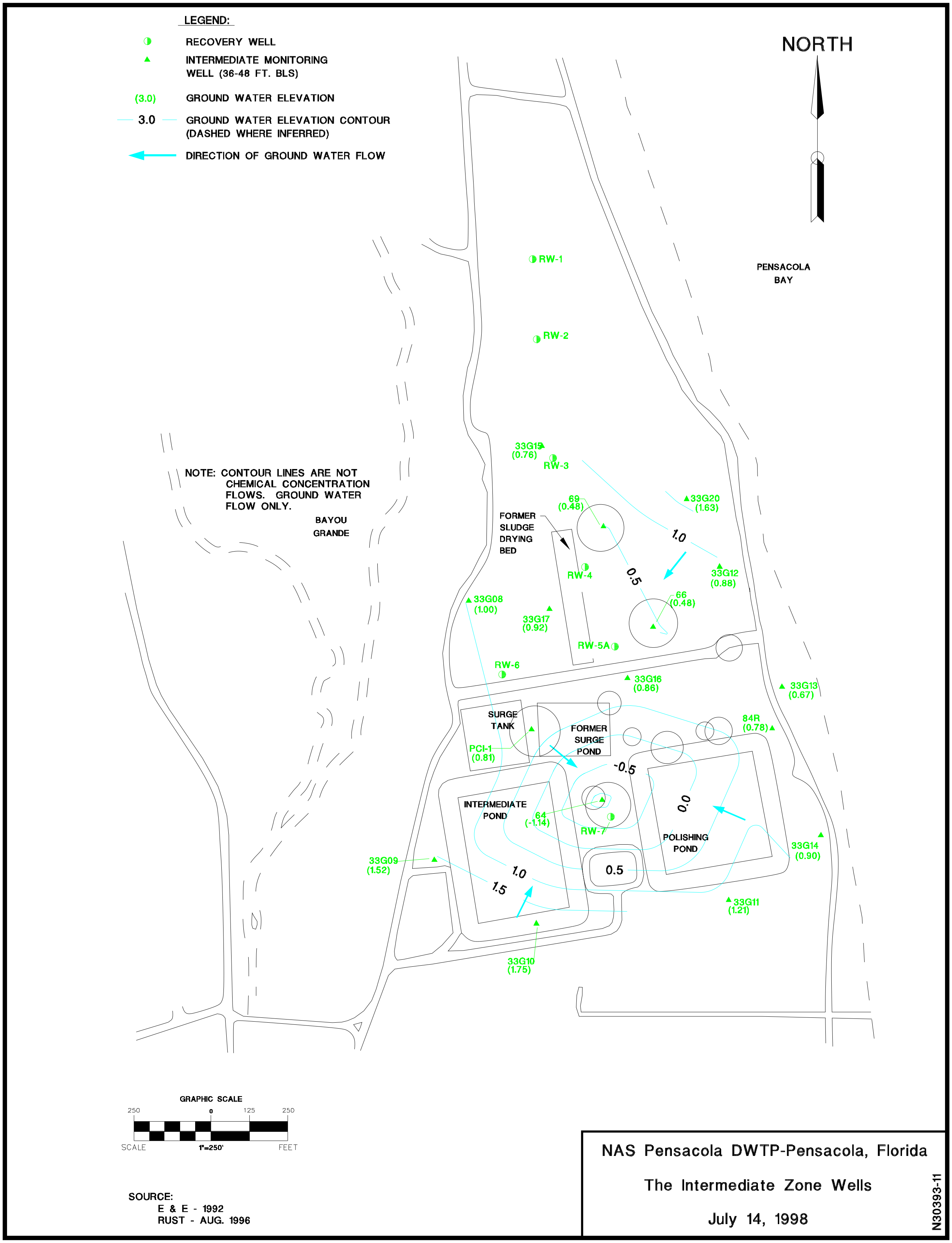

Figure 2. Intermediate Zone Monitoring Well Network

Appendix C
Statistical Methods

Appendix C—Statistical Methods

Throughout all phases of a groundwater monitoring program (including the establishment of DQOs, the preparation for the initial sampling event, and the continual reassessments while the program progresses), data are evaluated to answer the objectives of the investigation. Techniques used to evaluate groundwater monitoring results require groundwater data to accurately characterize site conditions and require data evaluations to justifiably answer project objectives.

To obtain the most accurate evaluations, data must portray site conditions as closely as possible; otherwise, evaluations are not informative (if you put "garbage data" into the analysis, then you get "garbage answers" out of the analysis). One way to minimize decision errors is to ensure that precision, accuracy, representativeness, completeness, and comparability (PARCC) criteria are met with respect to the analytical data.

Statistical methods are recommended in all phases of the program as a means for evaluating data. These methods are recommended because they provide accurate and defensible characterizations of groundwater conditions and can answer objectives of a monitoring program. Section 9.1 presents a number of statistical techniques to use when answering monitoring objectives. Because decision rules are specialized for each monitoring program, this section focuses on the tools useful for answering the most typical objectives of a monitoring program.

C.1 What Type of Data Do I Have Available? Does It Represent Site Conditions?

Before data evaluations can be performed investigators must:

- Identify the type of groundwater data available—is it censored or uncensored; and
- Determine how to best represent site conditions with respect to handling non-detected results (NDs).

For accurate data evaluations that best represent site conditions, uncensored data should be used and proxy concentrations should be estimated. Details about identifying the type of data available and defining proxy concentrations are discussed below.

Identifying the type of groundwater data available. Laboratories can report analytical data in two ways, as censored or uncensored. Censored data are data reported numerically if the concentration is above a censoring limit (typically, the sample-specific quantitation limit, SQL), or reported as "not detected" (ND), or "less than" a censoring limit if the concentration is below the censoring limit. Uncensored data include all instrument responses both above and below the censoring limit. If there is no instrument response (as may occur for low-level organic analytes) the result is reported as ND.

With censored data, no quantitative information is available about a ND result (except that the result is less than the censoring limit) because no estimate is provided to quantify how much smaller the result is from the censoring limit. Although useful for data reporting and presentation, censored data complicate statistical analyses and data interpretation because a qualitative result ("ND") can not be used in calculations. Quantitative results are required; statistical analyses require the use of numbers, not attributes. Therefore, when data are censored, the censored values must either be ignored or proxy values must be assigned for NDs so that numerical values are available for computations (see next subsection about how to estimate proxy values). Assigning proxies requires assumptions about the distribution of NDs (e.g., all NDs are equal or NDs vary in a manner similar to results above the censoring limit). The assumption that all NDs are equal (which allows one to substitute ½ the censoring limit) can bias the estimated standard deviation for the data set, particularly when a substantial number of results are "ND" (see ASTM D-4210-89 for further discussion of this topic). Biasing such summary statistics will bias conclusions to statistical methods, which in turn may lead to incorrectly answering project objectives.

Using uncensored data for statistical computations (not necessarily for data reporting) prevents the need to assign proxy concentrations based on arbitrary algorithms (USEPA, 1992 and Gilbert, 1987). While measurements below the censoring limit may not indicate the presence of target analytes as reliably as measurements above the limit, uncensored measurements are better estimates of concentrations than any proxy concentration and allow for better characterization of site conditions by data users and decision makers. Censored data are still relevant for determining the presence or absence of a contaminant at a site.

Although it is appropriate to flag results that are below censoring limits, statistical literature, federal standards, and EPA guidance all advocate the use of actual uncensored measured concentrations rather than proxy values in statistical calculations. Uncensored data provide more accurate estimates of mean and standard error, thus allowing more accurate data interpretation and more accurate answers to project objectives. Despite these advantages in some cases, requesting uncensored data may increase the laboratory expense and require additional time and effort for data interpretation. Uncensored data are usually not available, or difficult to retrieve, for historical sampling events.

Listed below are references associated with the use of uncensored data:

- American Society for Testing and Materials (ASTM) D-44210-89.
- Gilbert, Richard 0., *Statistical Methods for Environmental Pollution Monitoring,* Van Nostrand Reinhold, New York, 1987.
- USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R-96/084, January 1998.
- . USEPA, Office of Emergency and Remedial Response, *Guidance for Data Useability and Risk Assessment, Part A Final,* 9285.7-09A, April 1992.

Defining proxy concentrations for NDs. Before statistical analyses and other data evaluations can be performed, proxy values must be defined for all NDs associated with censored data and for all “no response” results associated with uncensored data (see previous subsection about use of uncensored data). A frequently used method for estimating proxy concentrations (assigning ½ the censoring limit) may bias calculations such as the standard error. Alternative statistical methods are available and can provide more accurate estimates of summary statistics.

- A relatively simple method defines proxies as random uniform numbers between 0 and the censoring limit. The benefit of this approach is that the proxy concentrations will closely follow the distribution of measurements that could have been made by the analytical instrument.
- Other methods account for the data’s distribution and assume that all data, above and below the censoring limit, follow the same distribution. Examples of such methods are the “maximum likelihood estimation procedure” and the “probability plotting method.” Approaches that require distributional assumptions are accurate only when such assumptions are appropriate and valid.
- Another alternative method, called Cohen’s adjustment, adjusts estimates of the average and standard deviation for the NDs instead of estimating proxy values for each ND result. A rule of thumb for applying Cohen’s adjustment is that it handles cases with between 15% and 50% NDs. However, some practical difficulties may be encountered that produce elevated estimates of the average and standard error. A statistician should be consulted for additional guidance.

Sometimes no censoring limit is provided with data. An alternative “censoring limit” for uncensored data is to define censoring levels for each chemical as the minimum detected result, or as the smaller of the sample-specific method detection limit (MDL) and the minimum detected result. For censored data sets where only project-specific reporting limits are available, the minimum of the J-flagged result for the given analysis can be used. In each case, proxy values can be assigned using the methods described above. For censored data, however, the distribution of J-flagged values should be examined for unusually low J-flagged results that may set proxies at inappropriately low levels (especially if the minimum J-flagged result is used as a proxy value).

Listed below are references associated with the various techniques for defining proxy concentrations:

- Gilbert, Richard 0, *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, 1987.
- (For a discussion of Cohen's adjustment): USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis,* EPA QA/G-9, EPA/600/R-96/084, January 1998.
- Helsel, Dennis R, *Less than Obvious: Statistical treatment of data below the detection limit*, Environ. Sci. Technol., Vol. 24.
- Helsel, Dennis R. and Cohn, Timothy A., *Estimation of Descriptive Statistics for Multiply Censored Water Quality Data,* Water Resources Research, Vol. 24, No. 12, pp.1997-2004, December 1998.
- Rao, S. Trivikram; et al., *Analysis of Toxic Air Contaminant Data Containing Concentrations below the Limit of Detection,* J. Air Waste Manage. Assoc., Vol. 2, pp. 442-448, 1991.

C.2 What Statistical Techniques Should I Use to Achieve Program Objectives?

This section provides a number of statistical methods that can be used to answer typical groundwater monitoring program objectives. This section is set up in terms of potential objectives, and presents the statistical methods most appropriate for answering each objective.

Scenario 1: How can I visualize data in order to evaluate and report results?

There are a number of methods of plotting data, including:

- Box plots of groundwater concentrations;
- Spatial maps of groundwater concentrations; and
- Time or trend plots of concentrations.

These plots can illustrate an enormous amount of information including, but not limited to, what is the range of concentrations, where are extreme concentrations located, how have plumes been identified, what potential trends exist, and how different are upgradient and downgradient concentrations. The plots are simple to create and evaluate and are extremely useful for summarizing information and conclusions associated with evaluating groundwater monitoring data. These plots are discussed in more detail in Section 7.

Scenario 2: How can I identify well concentrations that exceed regulatory limits?

Groundwater monitoring programs are generally designed to determine when groundwater concentrations of certain constituents are above regulatory limits (such as risk-based concentrations, state or federal standards, maximum concentration limits, water quality criteria, etc.). There are several methods for comparing concentrations to these levels, depending on the project objectives.

If the objective is to simply identify chemicals with detected result(s) that exceed the regulatory limit, it may be enough to compare each detected result to the regulatory limit. This method is simple. With minimal effort, summaries can be produced showing how many detected results exceed the criteria. However, this technique is unforgiving when it comes to infrequent anomalous, high values.

If the objective is to identify chemicals that have some percentile of concentrations (say, at the 90^{th} percentile) that exceed the regulatory limit, then an upper tolerance limit (UTL) is more appropriate. An UTL estimates the upper bound of a specified percentile of a data set (such as the 90^{th} percentile) with a given level of confidence. An upper tolerance limit calculation is based on the distribution of the groundwater data. If this UTL does not exceed the regulatory limit, then this limit provides a high level of certainty that the specified percentile of the groundwater data does not exceed the regulatory limit.

If the objective is to identify chemicals that have concentrations typically (on average) greater than the regulatory limit, then a one-sample means comparison should be used. A one-sample means comparison determines if concentrations are, on average, greater than regulatory criteria. Appropriate one-sample means comparisons are statistical tests such as the one-sample t-test and the signed-rank test. The type of one-sample means comparison performed depends on the distribution of the groundwater data. If the result of a one-sample means comparison is that the average concentration does not exceed the regulatory limit, then the comparison provides a level of certainty, given a desired level of confidence, that the average does not exceed the regulatory limit.

Listed below is a general reference text that contains details for calculating UTLs and for performing one-sample means comparison tests:

- Mason, Robert L., et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science,* John Wiley and Sons, New York, 1989.

Scenario 3: How can I identify outliers or extreme concentrations?

Statistical methods that identify outliers are useful for classifying extreme concentrations— results that are extremely small or large compared to the rest of the data. Statistical outliers can be identified using a box plot or an outlier test. Box plots are graphical tools for displaying extreme concentrations as well as the central tendency and variability of the data. Using a box plot, investigators can identify more than one result as an outlier; and, outliers can be present at both ends of the concentration range. Figure 7-1 provides an example of a box plot and its outliers. An outlier test is provided by EPA (*Statistical Analysis of Ground-water Monitoring Data at RCRA Facilities*, April 1989, and *Statistical Analysis of Ground-water Monitoring Data at RCRA Facilities: Addendum to Interim Final Guidance*, June 1992). Unlike box plots, this test is limited to identifying one point as an outlier. This outlier test can identify an outlier under one of two scenarios— the maximum concentration is an outlier, or the minimum concentration is an outlier.

Once outliers are identified, the project team should review outliers and determine why such unusual concentrations have been detected. Statistical outliers should not be removed from any data evaluations unless a specific reason for the abnormal measurements can be determined. For example, valid reasons for removing statistical outliers include evidence that they are the result of contaminated sampling equipment, laboratory errors or transcription errors. If a plausible reason can not be found for removing a statistical outlier, the result should be treated as a true, but extreme value. Although the value should not be excluded from further data evaluations, the additional evaluations should account for these extreme values so that they do not unduly influence statistics such as the mean.

Listed below are references associated with identifying outliers:

- Devore, Jay L, *Probability and Statistics for Engineering and the Sciences*, Brooks/Cole Publishing Company, 1987.
- USEPA, Office of Solid Waste Management Division, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities*, PB89-151047, EPA/530-SW-89-026, April 1989.
- USEPA, Office of Solid Waste Management Division, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities: Addendum to Interim Final Guidance*, EPA 86-W0-0025, June 1992.

Scenario 4: How can I identify differences in concentrations between downgradient and upgradient wells, or differences in concentrations between current and baseline data?

Generally, when two sets of data are compared, several statistical comparisons can be performed—two-sample means comparisons, individual comparisons, and quantile tests. Depending on how the DQOs are stated, either all, some, or just one of these comparisons should be performed.

If the objective of the program is to identify any chemical with an average downgradient concentration that exceeds the average upgradient concentration, then a two-sample means comparison is appropriate. Two-sample means comparisons determine if downgradient concentrations are, on average, greater than upgradient concentrations. They are performed using tests such as the two-sample t-test and wilcoxon rank-sum test, depending on the downgradient and upgradient data distributions. Analytes that show downgradient concentrations do exceed, on average, upgradient concentrations, or analytes that have low power for this comparison should continue to be monitored. Only those chemicals that have high power associated with the comparisons and that show average downgradient concentrations do not exceed average upgradient concentrations should be considered for removal from the analyte list.

If the objective of the program is to identify cases when *any* downgradient concentrations differs from concentrations seen in upgradient wells, then an individual comparison or a quantile test is more appropriate. Individual comparisons determine if individual downgradient results indicate the presence of a "hot spot" relative to upgradient concentrations, and are performed by comparing every downgradient result to an upper tolerance limit (UTL) calculated from upgradient data. An UTL estimates the upper bound of a specified percentile of the data set (such as the 95th percentile), with a given level of confidence, and is based on the distribution of the groundwater data. This individual comparison is preferable to the quantile test when an investigator wishes to identify concentrations from specific well locations exceeding upgradient concentrations. A quantile test provides a way to identify if some proportion of downgradient concentrations have shifted above upgradient concentrations. This test can detect shifts in downgradient concentrations that may not be extreme enough to cause the two-sample means comparison to show a statistically significant difference between downgradient and upgradient concentrations. The quantile test compares the upper percentiles of downgradient concentrations to the upper percentiles of upgradient concentrations, to test whether some specified proportion of the downgradient concentrations are significantly larger than the upgradient concentrations.

Each of these comparisons is useful and provides different information about the data. Two-sample means comparisons provide an overall picture of the differences between downgradient and upgradient data ranges. Individual comparisons provide information about "hot spots" for specific well locations and chemicals. Quantile tests view downgradient results as a whole, rather than as individual results. Only the means comparisons and individual comparisons, though, provide a systematic way of quantifying decision uncertainty.

If baseline data are available, then similar comparisons can be performed between current groundwater concentrations and baseline concentrations. These comparisons to baseline should be used to understand how groundwater concentrations have changed since the last time baseline concentrations were taken.

Listed below are references for the two-sample means comparison, the UTL, and the quantile test:

- Mason, Robert L; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.
- USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R-96/084, January 1998.

- NUREG-1505, Nuclear Regulatory Commission (NRC), 1997a, *A Nonparametric Statistical methodology for the Design and Analysis of Final Status Decommissioning Surveys*, Washington D.C.: Nuclear Regulatory Commission, 1997.

Scenario 5: How can I identify differences in chemical concentrations among wells or identify differences in concentrations among multiple chemicals?

When more than two sets of data are compared, the appropriate statistical method to use is an Analysis of Variance (ANOVA) in conjunction with multiple comparison tests or contrast tests. An ANOVA is similar to a two-sample means comparison (as described in Scenario 4) except that averages for several different groups can be evaluated simultaneously. The concept behind an ANOVA is to list all possible contributors to variability (e.g., well to well differences, gradient to gradient differences, chemical to chemical differences) and then test which sources contribute most to the overall variability in the concentrations. If a given source of variability contributes more than could be expected due to chance alone, it is concluded to be statistically significant. For example, if the variability in concentrations from one well to the next is large relative to the overall variability, then the well-to-well differences are said to be statistically significant. The specific type of ANOVA performed depends on the most appropriate statistical distribution assumption and on the different sources of variability that are included in the ANOVA. If results from an ANOVA show that significant differences exist (such as significant well-to-well differences), then a multiple comparison test can be performed to identify which wells, on average, differ and which wells, on average, are similar. There are a number of multiple comparison tests. Some of the more frequently used tests are the Duncan's multiple range test, Tukey's significant-difference test (SDT), and Fisher's least significant-difference test (LSD). Contrast tests are similar to multiple comparison tests, but they can be developed to compare a combination of results to another combination of results. Contrasts are particularly useful when investigators want to identify if concentrations from one downgradient well exceeds concentrations associated with all, combined, upgradient wells.

An ANOVA may be useful in instances where it is suspected that concentrations or trends in concentration of one or more contaminants are related in some way, for example as in the degradation of TCE and the production of daughter products such as cis-1,2 dichloroethene. Statistical verification of such trends can have important implications for remedial design and operation as well as regulatory approvals.

Listed below are references for the ANOVA, multiple comparisons tests, and contrasts:

- Mason, Robert L.; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.
- Snedecor, and Cochran, *Statistical Methods,* Iowa State University Press, Ames, IA, 1989.

Scenario 6: How can I test for a trend?

Recommended statistical approaches for assessing trends are the Mann-Kendall test and regression analyses, combined with visual inspections of graphical plots. Typically, spatial and temporal trend analyses start by visually inspecting plots of the results for a well or group of wells over time or as a function of distance from the source. Visual examination of such data is a highly sensitive means of detecting trends or potential trends in the data. Statistical tests can then be used to verify the significance of any observable trends by calculating the likelihood that the trend might have resulted purely from random variability. Attractive options for assessing the significance of trends noted in visual examination of concentration versus time plots is the Mann-Kendall test or a regression analysis.

The Mann-Kendall test can be interpreted as a test for an increasing or decreasing trend of concentrations as a function of time. This test is useful because it does not require that data be collected at equally spaced time intervals. This test has few statistical assumptions (such as an assumption of normality), is robust against one or two anomalous data values, can easily accommodate non-detected results, and is easy to interpret. However, one of its strengths is also a potential weakness. That is, the actual concentrations themselves are not taken into account. For this reason, the Mann-Kendall trend test is always accompanied by graphical presentations of the data. Also, this test for trend is typically not performed on a small number of concentrations; a rule of thumb is to perform trend analyses at least 4 samples.

Modifications to the Mann-Kendall test can be made to accommodate multiple measurements per well per sampling event or to correct for seasonal effects. These modifications to the Mann-Kendall test would be appropriate if pronounced seasonal variation were noted in monitoring data or if duplicate samples were to be included in the analysis. One drawback to correct for seasonal effects is that a longer time series of data is needed before statistical analysis can be usefully implemented.

Regression analyses can also identify trends. Such an approach involves constructing a model to predict concentration as a function of time (typically assuming linearity). If the model provides a good fit to the data and there is a predicted increase (or decrease) in concentration as a function of time, then the trend can be said to be significant. Regression analysis can be biased by outliers, such as anomolously high results. Also, purely linear models may not accurately represent trends in contaminant concentrations, which are often log-normally distributed. While these limitations can be addressed, an additional level of effort is required to assess the statistical properties of the data and properly format all results for the analysis.

The Mann-Kendall test should be applied as the first step in assessing trends. Regression analysis may be appropriate for assigning numerical values to trends identified as significant, as in calculating natural attenuation rates, contaminant mass removal, or rates of plume advance or retreat.

Listed below are references for the Mann-Kendall trend test and regression analysis:

- Gilbert, Richard 0., *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, 1987.
- USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R-96/084, January 1998.
- Mason, Robert L.; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.

Scenario 7: How can I evaluate data spatially and what can I gain from such an analysis?

Spatial statistical methods, or geostatistics, can be applied to groundwater monitoring data to help in:

- Defining plume(s); and
- Providing a basis for not continuing to monitor a well and/or a chemical.

Two related statistical tools are useful in spatial evaluations: semivariograms and kriging. Semivariograms are plots that provide information about the spatial correlation across a region. That spatial information is used by kriging to estimate concentrations at unsampled locations. Kriging maps can be evaluated to obtain a better understanding of the spatial pattern of contamination across a region that may not be apparent just by mapping individual concentrations.

Defining plume(s). Semivariograms can help define plume(s) by quantifying relationships between samples taken at different well locations. Strong spatial patterns that can be interpreted based on site knowledge may suggest groundwater regions should be considered as separate statistical populations. Separating wells into various regions or plumes can decrease the variability of concentrations and can allow for more accurate statistical tests and decision-making. This also provides valuable information for effective remedial design by distinguishing areas that require remediation from those that do not.

Providing a basis for not continuing to monitor a well and/or a chemical. Kriging maps can be used to delineate areas of contamination and to develop decisions about further sampling. These kriging maps can provide a powerful visual argument that the current delineation is either adequate or not; this can be useful in discussions with regulators. Uncertainty maps (maps of uncertainties associated with kriging predictions) can indicate whether additional sampling is useful. Also, if estimated chemical concentrations are substantially lower than comparison values (regulatory limits, upgradient UTLs, etc.), even after accounting for uncertainty, then it may not be necessary to collect additional samples even when sampling is sparse across that area or well.

Listed below are references for these spatial analyses:

- Clark, I., *Practical Geostatistics,* Applied Science Publishers, London, 1979.
- Gilbert, Richard O. and Simpson, J. C., *Kriging from Estimating Spatial Pattern of Contaminants: Potential and Problems*, Environmental Monitoring Assessment, Vol. 5, pp.113-115, 1985.
- Journel, A. G., and Huijbregts, C. H. J., *Mining Geostatistics,* Academic Press, New York, 1978.

Scenario 8: How can I obtain the power achieved by a statistical method?

Power can be estimated only when statistical methods are performed. Before discussing power much further, the fundamentals of statistical tests are presented. This provides a basis for the explanation of power.

A statistical test requires a null hypothesis and alternative hypothesis. Generally, a null hypothesis is a hypothesis of no change and an alternative hypothesis is a hypothesis of change (Mason, Gunst, and Hess, 1987). There are two possible ways to have an incorrect answer:

- Rejecting the null hypothesis when the null hypothesis is true (i.e., stating that there is a change, when no change has truly occurred). This type of error is called a Type I error.
- Accepting the null hypothesis when the null hypothesis is not true (i.e., stating that there is no change, when a change has truly occurred). This type of error is called a Type II error.

Statistical tests can not control these two types of errors. So, a test is set up in a manner that Type I errors are considered the more serious error and are controlled by the test. Statistical tests limit the frequency of Type I errors by setting a level of confidence, such as a 95% level of confidence. This level of confidence means that we want to be 95% certain that we correctly accepting the null hypothesis when the null hypothesis is true. Statistical tests are set up so a Type II error is not as serious an error, so Type II errors are not controlled. However, after a test is performed, an estimate can be computed to represent the frequency of Type II errors by calculating the power of a test. The power of a test describes the certainty associated with correctly rejecting the null hypothesis when the null hypothesis is not true. The table below illustrates the types of errors and correct decisions associated with statistical tests:

Conclusions associated with Statistical Tests

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">True Hypothesis (what has truly occurred)</td></tr>
<tr><td>Null Hypothesis True</td><td>Alternative Hypothesis True</td></tr>
<tr><td rowspan="2">Test Decision</td><td>Do Not Reject Null Hypothesis</td><td>Correct decision
(level of confidence)</td><td>Type II error</td></tr>
<tr><td>Reject Null Hypothesis</td><td>Type I error</td><td>Correct decision
(power)</td></tr>
</table>

Power of a test is calculated by estimating the probability of rejecting the null hypothesis when the null hypothesis is not true. The method for calculating power is specialized for each statistical test. For further information about estimating power, refer to the general reference text listed below:

- Mason, Robert L.; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science,* John Wiley and Sons, New York, 1989.

The importance of estimating power is its relationship with sample size. As the number of samples increase, the power of a statistical test increases (assuming other factors remain constant). In fact, power formulas can be used to identify the number of samples necessary to achieve a specified amount of power for a given statistical test. For all phases of groundwater monitoring, we highly recommend determining the number of samples needed to achieve a certain level of power. This will ensure that data evaluations provide the most informative and accurate results as possible.